PREEMPTION - A VIABLE STRATEGY?

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PREEMPTION - A VIABLE STRATEGY?

by

Lt. Louis J. Oswald, III

Submitted in partial fulfillment of the

Requirements for the Degrees of

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AND

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ABSTRACT

This report develops a structure that may be used to define, evaluate and eventually implement a preemptive dispatching strategy for the police.

It is assumed that there are two priorities of customers, urgent and nonurgent, and that if prescribed spatial conditions are met, the patrol unit serving the nonurgent customer will be interrupted and dispatched to the urgent caller. The strategy has been defined such that the nonurgent customer will immediately have another server assigned. A spatial model, based on an $M/G/\infty$ service system, is created to define the spatial context of preemption.

The spatial information is integrated into a Decision Analysis of a preemptive dispatching strategy. A decision tree is developed that delineates the dispatching process. Then a Group Multiattribute Utility Function is formed, by nesting two, four-attribute Group Multiattribute Utility Functions of the police and the customer, to evaluate alternative actions. The function includes subjective as well as objective measures. An anaylsis of a feasible computer program package is presented.

Numerical estimates are used to illustrate the properties of the structure that has been developed to describe preemptive dispatching. The model is seen to be a valuable tool that can be used to analyze and evaluate a preemptive dispatching strategy. It not only provides a means to define the problem, but it also increases the decision maker's understanding of the complex interactions that will occur.

The conclusion will suggest simple data collection and operational procedures that might be used by a police department to initiate "first-step", formal preemptive priority dispatching strategy.

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I. INTRODUCTION

A. Introduction

Millions of dollars are being spent in the U.S. on the development and installation of sophisticated communications networks and computer-aided dispatching (CAD) systems like SPECIAL POLICE RADIO INQUIRY NETWORK (SPRINT) in New York City, Computer Assisted Bay Area Law Enforcement (CABLE) in San Francisco, and the proposed Newark Computer Command Control Communication (NC4) system in Newark, New Jersey, to reduce communications delay and aid the dispatcher. St. Louis is experimenting with automatic vehicle monitoring (AVM) systems that will continuously locate a unit's position. This will reduce travel time by always allowing the dispatcher to select the closest unit. Congestion in radio communications is being reduced by the use of digital mobile units which send precoded messages merely by pressing a button. Cities are attempting to provide their customers with the best service money can buy.

However, although most of the technological research is being funded by the federal government through agencies like the LEAA, many cities cannot afford to purchase new equipment and/or hire the additional personnel that public demand warrants. It now costs considerably more than $100,000 per year to man a single two-man patrol car 24 hours a day, seven days a week.[1] The ever-enlarging police force is ending, as is evidenced by the recent cutbacks of the New York City Police Department.

Yet, the cities must somehow meet the public's ever-increasing demand for service.[2]

It is the basic premise of this paper that the public ultimately decides the exact nature of the police service they receive. If they want "better" service with many patrolmen they will vote for increased taxes. If they want "better" service but are unwilling to hire more police, assuming that the current service is being run conscientiously, they will accept concessions that reflect their priorities.

B. Background on Police

The police began as roving patrol within European and then American cities over 200 years ago. The townsmen's original intent was that the police would protect them from thieves, and maybe prevent crime before it occurred.

However, over the years the police role has changed. The police are not only responsible for apprehending criminals and deterring crime, but they have assumed many auxiliary responsibilities which dominate their day like: giving first aid, providing ambulatory service, settling domestic quarrels, delivering babies, aiding in lockouts, clearing blocked dirveways, and rescuing cats from trees to name a few. In fact, only about 20% of the calls received involve crimes, the other 80% are for related services the police provide.[3]

It is difficult to pinpoint why the police have been left with the awesome responsibility of regulating society's problems both big and

small. The fear engendered by crime has certainly had some effect. As early as 1968, a national survey indicated that crime was the major domestic problem facing Americans.[4] In fact, it has been said that the omnipresence of crime in the late 1960's changed American's unquestioning acceptance of the good of conflict and change toward a desire for congruence.[5] At the same time, the church, school and family have experienced an overall erosion of authority.[6] The combination of these two dramatic changes caused the public to seek national leadership in Police Enforcement, a goal they had rejected less than 10 years earlier.[7]

Consequently, Americans have come to rely on the police as the sole mechanism responsible for law and order. With each new "crisis," the police task increases. If there were no longer crime, it is not clear that we would not need the police.

This attitude tends to overload the capabilities of the police response system. During certain periods of the day the police cannot immediately dispatch, that means send, a car to a call for service because every police response unit (eg. car, squadron, supervisor, etc.) is busy. Ultimately, it requires that a decision is made as far as what service is emphasized. Either the caller must wait or some other strategy must be adopted to handle calls.

C. Dispatching

C.1 Introduction

Consequently, the police are faced with the problem of how to allocate their available resources most appropriately. The dispatching

strategy that is employed is the primary method that can be varied to accomplish a variety of goals. It allows the system to vary the order in which calls are serviced and may even determine what calls are serviced.

The strategy that was used for many years was basically a first come, first serve (FCFS) strategy. The FCFS serving strategy is simple; there is no chance at making an error because everyone is treated the same and their average waits are the same, and most important, the public is accustomed to this means of service and feels it is equitable. However, it has a great disadvantage as soon as all servers become busy. At this time important (urgent) callers will be forced to wait to receive service until unimportant (nonurgent) callers', who are ahead of them, service is completed. The urgent customer is forced to pay a high price for an "equitable solution."

The problem that occurs when an alternate strategy is proposed is that while the public is demanding everincreasing amounts of public services, the police not excepted, they do not want to pay additional taxes for these benefits and are unwilling to accept any curtailment of these services. It is felt that this attitude is unreasonable because public services cannot continue to expand.

C.2 Options

There are two possible general alternatives to be followed in altering current dispatching strategies, the first is prioritization;

the second is screening. Prioritization changes how service is given; screening changes what service is given - or who receives it.

Prioritization is defined to be the formal determination of a call's urgency. For instance calls may be of two priorities, urgent or non-urgent. In a (two priority) system, according to predetermined criteria, all calls received will be assigned to one of two priority categories.

Screening, on the other hand, also requires the analyses of incoming calls, but in this case certain calls are disregarded. Using a set of prespecified criteria, the complaint operator "screens out" calls that are deemed unimportant, or not requiring on-scene police service. Only calls that pass the screening test receive service.

C.3 Screening

Screening is a severe strategy used to improve service to a specific group of customer. It is a policy that strictly rations the service that is provided. It is already used for evaluating calls for hospital ambulance services and in some city police departments. In fact, in New York City with the advent of 911, which is a central emergency telephone number, the New York Police were forced to intensify their existing screening process to maintain a manageable workload.

C.4 Formal Priority Dispatching Strategy

Formal priority dispatching is a strategy that is an outgrowth of prioritization. Under this policy all calls that are classified to be in the urgent category are serviced prior to any call in the nonurgent grouping. Service is never interrupted once it is begun.

The advantage to this strategy, of course, is that the urgent customer receives service quicker than he would under a FCFS strategy (when a queue has formed) and nonurgent customers will receive service although the wait may be extremely long. However, the urgent customer can still experience a long wait.

It is not unrealistic to propose that calls for emergency service be scrutinized. Decision makers (d.m.'s) are deciding whether or not an individual really needs emergency service. They make decisions that could result in serious error, including a person's death. The department of transportation is only one example of a public service that has already determined a "value of life."

C.5 Actual Dispatching Strategy

In reality, it is uncommon to find a police department that uses a FCFS strategy or a formally defined priority dispatching strategy, except those with CAD. Instead the strategy used is an informal mix of FCFS and priority dispatching. Calls are serviced as the dispatcher's experience dictates. The complaint operator decides a call's priority, but it is up to the dispatcher's discretion when the call receives service.

In fact, when all units are busy and an urgent call is received, it is not uncommon to hear the dispatcher ask if any car is available for servicing an urgent call. In essence, he is asking one of two questions: (1) Has any car really completed his job? or (2) Will someone preempt themselves? In turn, it is not uncommon for a unit to reply that it "is" available and take the job. This is an informal method of preempting as service to the nonurgent customer is interrupted or unfinished paperwork is delayed.

D. Preemption

Preemption is a strategy which uses prioritization whereby service is immediately given to an urgent customer by interrupting the service of a low priority customer. The customer who has had his service interrupted is said to have been preempted. All servers need not be busy before a low priority customer is preempted, although this decision depends on specific criteria established beforehand.

The most well known use of a preemptive priority service strategy is in a hospital emergency room, when a severely injured patient is interrupted to provide immediate attention to the critically ill person.

The primary advantage of preemption is that there is almost no possibility of a queue delay for the urgent customer as was the case with a formal priority dispatching strategy. Also, the nonurgent customer will receive service, which was not the case with a screening policy.

A drawback is that the nonurgent customer's waiting time increases and there is the possibility, although it could be prohibited, that a customer's service could be interrupted more than one time.

Intuitively, it is simple to extend this concept to police dispatching. With a preemptive dispatching strategy, if a police officer is trying to get a cat out of a tree and a robbery occurs down the street, the police officer is preempted by the dispatcher and proceeds to the robbery, leaving the person whose cat is in the tree until some later time.[8]

Perhaps preemption can be used as a dispatching strategy that is a reasonable compromise between the results of screening and a formal priority dispatching strategy to improve system efficiency, effectiveness and equity.

Advantages of Preemption. There are many intuitive qualities that are appealing about preemption. (1) It is easy to grasp conceptually. Preemption can be conceptualized as a means to provide better service for an "urgent" customer. In general, if there is a busy nonurgent unit located closer to an incoming urgent call than any free unit ("closer" is according to specific criteria), the nonurgent caller is interrupted and the unit is sent to the urgent caller. Under this strategy, according to probabilistic decision criteria, the system can provide more rapid service to customers with the most "need." (2) Also, the strategy requires no additional outlay of money for men or machinery. (3) A more rapid arrival rate tends to quell citizen apprehension while increasing the chances of apprehension in criminal cases. (4) Any increase in arrests, charges and convictions are highly visible testimony of police effectiveness. (5) In addition, preemption is a logical extension of CAD and AVM. (6) It is likely preemption will boost officer morale, because it affords more opportunities to provide critically needed service when it is most needed, not when it is too late. (7) Furthermore it may be possible to improve system effectiveness with preemption, even more, by changing the prioritization criteria. Current priority dis-

patching strategies base selection primarily on the seriousness of the crime. The FBI Part I and II Crime Indices are representative of the distinctions that are made. Certainly this seems reasonable, until one realizes that a number of these crimes occurred in the distant past. For example, many robberies that occurred Friday aren't reported until Sunday night when people return from a vacation. Meanwhile, as this "old" robbery is given priority, there is a caller who is reporting a Part II crime, where the suspect is still "on the scene." Perhaps "in progress" might be a good additional criteria for preemption.

Various statistics on apprehension would tend to support this hypothesis. Crimes that are reported after they occur have a much smaller chance of arrest or conviction.

Consequently, "in progress" seems to intuitively be a consideration for preempting because there seems to be a greater chance of maximizing the benefits of the effort.

Yet, before a preemptive dispatching strategy can be implemented not only must the intuitive advantages be verified but problems and questions and a means to define and measure the effects of the strategy must be resolved.

For instance, it is difficult to define the situational boundary where preemption should or should not occur. Suppose the officer, in the earlier situation is helping an elderly lady into her home, because she has lost her key, and the same robbery occurs. Should the officer leave the lady? Certainly, if the officer returns in 10 minutes having arrested the robber, the lady and public would understand.

But how would the lady react if she had to wait one hour, or worse, if she were mugged? The answer is not at all clear.

The difficulty is that the consequences of the preemptive dispatching strategy, as with any police operational consideration, are unknown. We are dealing with a dynamic probabilistic system in both time and space. Results are uncertain and potentially catastrophic. There is risk involved. If the chances of victimization are too great it is hard to justify leaving the elderly woman to try to catch a robber.

This problem is reinforced with a preemptive dispatching strategy because it requires prioritization. A call must be assigned a priority, therefore the strategy will be no better than the accuracy with which this is done. Any bias or prejudice on the part of the complaint officer will significantly affect the strategy's success. In any event a public relations program will be needed in conjunction with preemption to insure that citizens understand why their service was interrupted.

Preemption will also have an impact on the service mechanism. The nonurgent customers queuing delay will increase. Officers will spend more time traveling to incidents and the number of radio communications will increase.

Lastly, a decision maker must recognize that preemption depends on both public and police acceptance of the strategy. The public may not approve of the inherent tradeoffs that are assumed. The police may purposefully circumvent a policy that breaks their old routine. It may be impossible to create a structure that describes the uncertainty of the

decision process and measures that adequately and accurately describe the multiple objectives and consequences of preemption to all concerned, and also help define the roles that will be necessary for the strategy to be successful.

E. Objectives

Preemption will be investigated as an alternate police dispatching strategy. It is specifically addressed at improving service to those with the most need when service is constrained by limited resources. It is intended to be a logical predecessor to current service strategies, rather than a totally new policy, so that it will be able to operate within the existing system with as little disruption as possible.

Specifically, I will describe a structure, that utilizes spatial modeling and Decision Theory, to develop, evaluate and implement a preemptive priority dispatching strategy in the police public service bureaucracy. The intent is to create a model and performance measures that will improve service to the system, while simultaneously providing incentive to both the police and public to create a more responsive, democratic public service. The special nature of a police service system will be emphasized. By creating a well defined model that is capable of including public opinion and explicitly recognizing the decision maker's choices of weighting the various groups, it is hoped that the administrator's policy considerations and alternatives are clarified and that his decisions will be brought into the open.

This is a multifaceted problem that demands an extensive understanding of both system mechanisms and the personal interactions that

occur. This means that not only most the impact of uncertainty be stressed, but also it is vitally important that the measures of effectiveness employed are appropriately related to the accepted police and public roles.

In particular it is recognized that it is critically important to understand the operation of the police department - or the system characteristics. An accurate perspective of the job a policeman performs and how he does it will clarify: (1) the likelihood of a preemptive dispatching strategy succeeding in the existing system (2) the structure that will be employed to describe the decision process.

Ultimately, an algorithm will be defined that will be capable of evaluating alternative dispatching decisions within a preemptive dispatching system. However, it will not replace the human dispatcher because it can only duplicate the mental checklist a dispatcher has developed through experience.

A goal of this study is to better understand fear and other "customer" feelings and assume an increased responsibility for second-order consequences of preemption. A designer must be concerned with the psychological and sociological impact of preemption, and to whom they occur. The decision of who determines which measures are used takes on added significance.

F. Expected Results

I feel preemption will be beneficial if the system as a whole is not penalized. By the system I am referring to high and low priority

customers, and the police. I expect average police workload to increase due to, at least, an increase in travel time; low priority travel time should increase due to delays introduced by preemption. But hopefully, the high priority customer will receive better service. If a minimum level of service that no customer is expected to receive is established and not exceeded, the tradeoffs that result should allow an overall improvement in system performance. In addition a decision process will have been identified that not only measures the effects of the process and its outcomes, but also delineates the decision makers thought process.

G. Organization

The orgnaization of the remainder of the paper is as follows: Chapter two develops a spatial model that can be used to define a preemptive situation. The concept of preemption in a spatial context and the assumptions that are necessary to construct the model are discussed. A spatially oriented $M/G/\infty$ service system will form the queuing basis for the model. A set of curves which reflect the costs incurred for every additional minute of delay in arriving at an incident is described. The curves for a two priority system are shown to be capable of defining a "preemptive situation." The important measures of a preemptive dispatching strategy are first developed in Euclidean measures. They include mean distances to the closest free or busy units. Then the model is changed to a more applicable right angle distance metric and the equations are re-derived.

Chapter three describes the general decision theory approach to a problem, then it develops the decision tree that will be used to evaluate a preemptive dispatching strategy. The process is broken down into three sequences: (1) answering the call, (2) classifying the call and checking unit states, and (3) dispatching a unit and its outcome. The tree that is formed relies heavily on the constraints that are inherent in the spatial model. The decision tree is modified to a size that can be supported by the available data. Any analysis utilizing all the proposed branches can not be justified at this stage because of the scarcity of data that is meaningful to preemption. Finally, probabilities are specified for the remaining branches of the tree.

Chapter four provides a discussion (prior to the selection of performance measures) of some of the system characteristics that must be recognized. It discusses problems with existing measures and what aspects of police service require emphasis. As has been mentioned, public and police acceptance of the dispatching strategy is a critical concern. A question of who should select what performance measures is raised. A citizen survey is suggested as a reasonable means to identify many important attitudes concerning police performance.

Chapter five discusses the performance measures that are chosen. The approach that is used first describes which groups of people are felt to be important, then measures that will satisfy their needs as well as the system's are identified according to the discussion in

chapter four. Eight performance measures, or attributes are proposed as an example of a possible multiple objective set of criteria for evaluating the outcome of an action.

Chapter six details the analytical process that was followed in constructing the multi attribute utility functions. First utility theory is discussed and eight single attribute utility functions are created. Then the four attribute utility functions for the police and the customer are formed. In turn, these four attribute multiattribute utility functions (MUF) are combined to form the overall system group multiattribute utility function (GMUF). Sensitivity analysis over a number of alternatives is performed to assure that they reflect the decisionmaker's (d.m.'s) true feelings. Finally, a means to "fine tune" a MUF is carried out of the overall system GMUF.

In chapter seven a spatial simulation is performed using the spatial model to identify preemptable situations. One hundred unit positions are generated randomly and uniformly throughout a 100 square mile area. Each unit has a status randomly assigned that reflects the proper utilization rate. Once a call occurs the closest free unit and any busy units located closer than the closest free one are identified. The associated preemptable area is identified and is checked to see if any free units are within it. All pertinent information is then displayed. For instance, the mean distances to the closest free, busy and replacement units are computed, along with the probability of preemption given a number of initial conditions, and other information.

Chapter eight describes a possible computer program package that could evolve from the first eight chapters. Information from the spatial simulation is used in the decision tree, and the specific alternatives of an action are evaluated using the overall system GMUF. A single example is used to illustrate the information that would be made available.

Chapter nine provides a discussion of the aggregate effects of preemptions. It describes the increased chance of error and means of circumvention associated with a preemptive dispatching strategy, as well as the means to measure the effect of preemption with regard to overall system efficiency.

Chapter ten is the conclusion.

A Glossary is provided at the end of the report to clarify terminology that is used throughout the paper.

There are appendices that detail the derivation of various performance measures, and the decision theory used, as well as discuss the use of NO SHOW and NO RESPONSE.

H. Relevant Literature

The literature that is relevant to the approach that will be taken in this paper can be found under three basic headings: (1) the provision of police emergency services, (2) preemptive queuing, and (3) decision theory.

H.1 Police Services

The problem of appropriately allocating police resources is not new. As early as the 1930's, Wilson[10] and Gourley[11], used analytical means,

mathematical modeling, to describe measures of effectiveness of police patrol allocation. They began by using "equal workload" as a criterion to evaluate the appropriateness of various patrol allocation strategies.

Then it was demonstrated by Growther and Shumate[12] that queuing analysis could provide an approach to better patrol allocation.

Basic works on queuing and the optimization of stochastic systems by Karlin,[13] Cox and Smith,[14] and Feller[15] were specifically applied to the problem of patrol patrol allocation by Larson.[16] For the first time in Urban Police Patrol Analysis a comprehensive approach that integrated demands for service, availability of units and the service discipline was used to define and evaluate the multiple objective problems of police service.

The Hypercube Model, which was proposed by Larson and has since been worked on by Campbell,[17] Larson,[18,19,20] Jarvis[21] and others, provides a sophisticated capability to estimate system operating characteristics in terms of queuing delays, travel times, workload, and cross beat dispatches. It has the capability to evaluate a wide variety of alternate system configurations which allows a subjective determination of the best strategy.

A brief overview of other work in the emergency service field can be found in Larson.[22]

H.2 Queuing Strategy - Preemption

The original works on a single server preemptive priority queuing system were done by Cobham,[23] Heathcote,[24] and Christie.[25] The work was then extended to a two queue case by Stephan.[26] Heathcote did additional work that extended the theory for several priority classes and then to include a multiserver queuing system. The theory of preemptive priority

queuing has been applied primarily to areas such as machine job scheduling with interference, as in Conway[27]. Many different queuing strategies have received attention in the evaluation of many different patrol dispatching strategies. However, in practice, a preemptive queuing strategy has only been used in Rotterdam[28]. The difficulty that must be overcome when one tries to apply preemption to a police response problem is to maintain the servers' identity. Examples and discussion of preemptive strategies that have been proposed for the police can be found in Larson[29,30].

Decision Analysis

The theory behind Decision Analysis is best explained in Raiffa[31]. It grew from a need to organize and systematically approach a decision problem under uncertainty. It was designed especially for complex problems where there are many probabilistic outcomes that need evaluation.

Work by von Neumann and Morgenstern[32] provided a means that was particularly well suited for creating and evaluating the performance measures to be used with the decision tree. Utility theory scales the decision makers' values such that the best decision is determined by noting the alternative with the greatest expected utility. It was possible to evaluate an action according to multiple objectives by the construction of multiattribute utility functions. Keeney[33,34] has done much work in identifying unique functional forms that can be verified with simple questioning. Kirkwood[35] has studied the problem of assessing group multiattribute utility functions.

Computer solutions of decision problems have been proposed by Gorry[36] and Schlaiffer[37].

Keeney[38] and Kirscher[39] have demonstrated some multiple objective group decision problems in which a decision analysis approach can be successfully applied.

Keeney[40] and Hauser[41] have demonstrated the applicability of decision theory in the public service sector.

Conclusions

We have noted that a great deal of effort, over many years, has been devoted to the allocation of police resources. Queuing theory and spatial modeling contribute significantly to the overall understanding of the problem. Models such as the Hypercube incorporate this information and provide comprehensive measures that can be used to evaluate specific strategies.

Nonetheless, other techniques of analysis have developed simultaneously and in parallel with the current methodology. Decision analysis is a method that would seem to be ideally suited as an alternate means to analyze a police dispatching strategy because of its probabilistic structure and its ability to cope with uncertain, multiple objective situations. Although, to my knowledge decision analysis has not been applied to police public services, it has been applied to other public services. Decision theory has the capability to include subjective measures, and it formally emphasizes the decision process more than any other existing methodology; both capacities would be of great value in police work.

Thus, with my interest in preemption, I feel that it will be valuable to investigate the applicability of Decision Theory as a tool to evaluate a preemptive dispatching strategy for the police public service bureaucracy.

II. SPATIAL MODEL

A. Introduction

In this chapter we will develop an analytical model describing the spatial conditions that must be met for a situation to be described as "preemptable." This will enable us to measure the impact of a preemptive dispatching strategy on the police response system and its clients.

B. Spatial Concept of Preemption

The basic spatial concept of preemption is quite simple. Upon receipt of an urgent call for service, if a unit busy on a nonurgent incident (a busy nonurgent unit) is located nearer to a new urgent call than the closest free unit, the nonurgent customer's service will be interrupted and the attending unit will be dispatched to the urgent call However, no matter how simple it may be to intuitively implement a preemptive strategy, the problem is that there is no yardstick to tell whether conditions would be "better" or "worse" than without employing preemption. It is difficult first to imagine how often a busy nonurgent unit will be located closer than the closest free unit. Similarly, it is hard to judge what this will do to the waiting time of the nonurgent customer or travel time, utilization and other standard measures of performance in police work.

A spatially oriented model is necessary to provide these measures. The first function of the model will be to define explicitly when a

preemptable situation exists. Its second function will be to allow measurement of the effects of preemption. With this information it is possible to analyze the theoretical spatial consequences of preemption and incorporate the data in further analysis. The mathematical model will form the foundation for the rest of the preemptive dispatching algorithm.

C. Model Assumptions

In constructing a mathematical model there are two primary concerns: (1) accuracy, and (2) tractability. Accordingly, the following assumptions will be made.

(1) There are two priorities of incoming calls: priority one and priority two. Priority one calls are urgent calls for service where urgent is to be defined to be not only those calls defined as "emergencies" under present emergency call criteria, but also (a) crimes that are not emergencies but may soon escalate to a serious situation, or where there may be a suspect on the scene, and (b) events that are not crimes but may be emergencies and/or in progress. For instance a call concerning a "suspicious person" may now be upgraded to an urgent priority, because it can be shown that many of these incidents escalate into breaking and entry and burglaries. In this fashion a more rapid response can be provided to calls in which the police can be most effective. Priority two calls will include all other calls.

(2) There are an infinite number of servers.

(3) Urgent and nonurgent calls for service arrive in a spatially Poisson manner with rates λ_1 and λ_2 respectively, where Spatially Poisson means demands are generated from a region of area A at rate λA calls per hour.

(4) The service times for urgent and nonurgent incidents are distributed in a general distribution with means $^1/u_1$ and $^1/u_2$ respectively, where $^1/u \equiv$ the mean total time to service an incident, u_1 is not necessarily equal to u_2.

(5) Free servers are distributed in a spatially Poisson manner due to random patrol. That is regardless of the number of servers that are busy the entire area will always be patrolled uniformly.

(6) The police dispatching system has CAD and AVM.

(7) Only nonurgent customers can be preempted and then only to provide a server for an urgent caller.

(8) A nonurgent customer can be preempted any number of times.

(9) If a nonurgent customer is preempted a replacement unit will immediately be dispatched to the caller to complete the service. Item (9) requires further explanation.

Preemption can be broken down into preemptive "resume" or preemptive "repeat" strategies. Under a preemptive resume strategy service to the interrupted customer is begun where it had ended. There is no need to repeat any portion of the service that had been done before. Under the preemptive repeat strategy, however, service must be re-initiated. In fact, preemptive repeat strategies can be described, mathematically, as preemptive repeat with, or without resampling.[42]

In the police contact we will immediately dispatch a replacement unit to try to insure a preemptive resume strategy is appropriate so that little service time is wasted and the only effect of preemption will be increased travel time and possibly a queuing delay. It is not unreasonable to expect that we could approach a preemptive resume strategy if the attending unit is first asked if they feel they can leave the scene. This methodology will allow the attending unit to assess the situation and insure it is stable so that the replacement unit will only have to provide additional counseling or check up on the situation.

In queuing theory the conditions I have described define a spatially distributed $M/G/\infty$ service system, meaning there are Poisson-distributed arrivals, general service times, and an infinite number of servers. This assumption contributes to the model's conputational convenience but entails a certain loss of detail and reality.

The advantage is that it can be proven (see Appendix A) that in a spatially oriented $M/G/\infty$ service system all busy servers are distributed in a spatially Poisson manner. Thus if $\rho_i \equiv \frac{\lambda_i}{u_i}$, the probability that there are K, pri i busy servers in an area A, is $P(K,A) \equiv \frac{(\rho_i A)^k e^{-\rho_i A}}{K!}$, by definition of a spatially Poisson process.

This is a valid assumption as long as there are enough servers in a city such that the probability that everyone is busy is very small - on the order of one or two percent. This implies that $\frac{\lambda_i}{uN}$ must be less than one otherwise calls would be arriving quicker than they could be served

and an infinite queue would result.[43] In this situation, when all units are busy, the patrol force is said to be "saturated."

The disadvantage in assuming that a spatially oriented $M/G/\infty$ service model is appropriate is that there is no queue of calls awaiting service. Not only is this an unrealistic assumption but it hides a distinct advantage of preemption. When there is no urgent caller queue, the primary advantage to preemption becomes the difference in travel time gained by dispatching a busy unit that is closer than the closest free unit. Thus, when comparing preemptive to nonpreemptive strategies, any advantage will be the result of the time advantage that can be derived from preempting.

Further assumptions that will be made in constructing the mathematical model are:

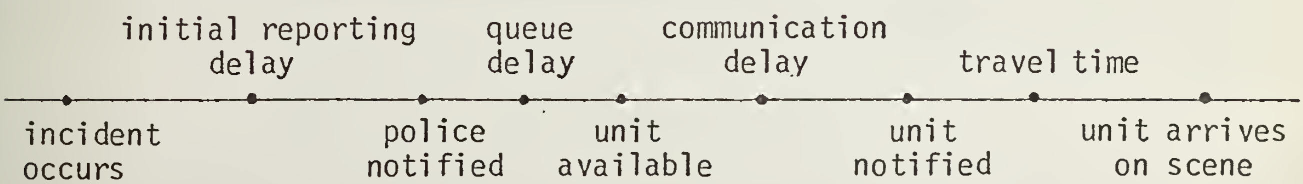
(10) There is no communications delay.

(11) There is no initial reporting delay on the part of either the victim or a witness.

(12) There is no difference in travel speed in the X and Y directions, although priority one travel speed (V_1) is greater than priority two travel speed (V_2).

(13) All calls will be answered.

Items (10) and (11) require additional explanation. A dispatching process in which queues exist can be diagrammed as seen below.



Initial reporting delay, queue delay and communications delay are all significant because they occur prior to a unit being dispatched. Consequently they directly affect when a unit arrives on the scene, which in turn has an important bearing on the degree of success of the service that is provided. However, there is no reason to suspect that the distribution of these delays would be different for various dispatching strategies. Consequently, their effect will be the same on each strategy and they can be ignored.[44]

D. Construction of the Model

We are now in a position to begin constructing the spatial model of preemption. Initially, all distances will be Euclidean to aid in visualizing the strategy.

The following notation will used:

• ≡ location of incoming urgent call

X ≡ location of closest nonurgent busy unit

O ≡ location of closest free unit

The following distances are defined:

D_f ≡ the distance from an incoming urgent call to the closest free unit

D_b ≡ the distance from an incoming urgent call to the closest busy nonurgent unit

D_r ≡ the replacement distance from the closest eligible free unit to the preempted caller.

The spatial picture of a particular situation may appear like Figure 2-1.

Certainly, it is reasonable to consider preemption only if $D_b \leq D_f$, that is when the closest free unit is farther from the incoming urgent call than the <u>closest</u> busy nonurgent unit. Logically a preemptive dispatching criterion should be a function of the spatial relationship between the closest busy and closest free units, as measured by distance or time. If a means existed to measure the distinction that existed when the respective units were in various spatial positions, then a means would exist to define a preemptive situation.

The assumptions that were made in defining nonurgent calls demonstrate that preemption is being geared to provide service to the incidents which are most likely to benefit from the special attention they receive. Thus there is an implied measure of importance that is attributed to the length of time, due to the distance a unit must travel, a unit must wait for service. The importance will be a function of the calls urgency.

Let us try to imagine an intuitive "cost" curve where cost (weight) is assigned to each minute of delay incurred while responding to a call for service. If service could be provided very rapidly, small differences in the arrival time are probably relatively unimportant. However at some point there will be a region where a few seconds difference might make a critical difference in the outcome of service. For instance, it may be a life or death situation. Finally, however, at some point

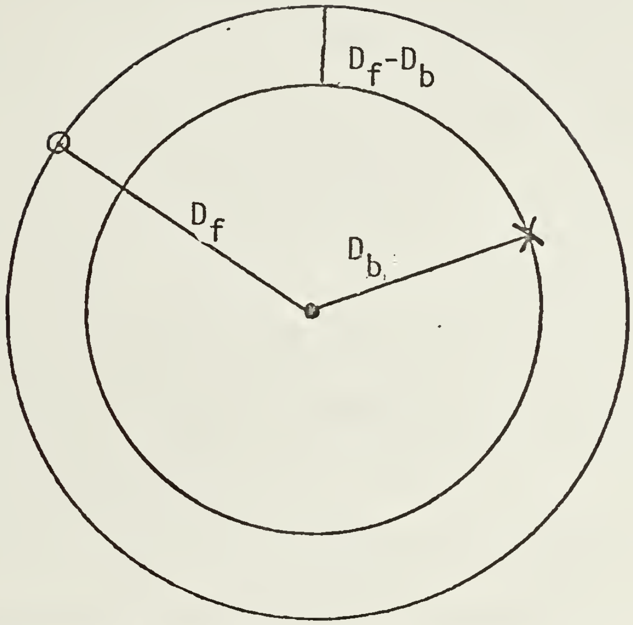
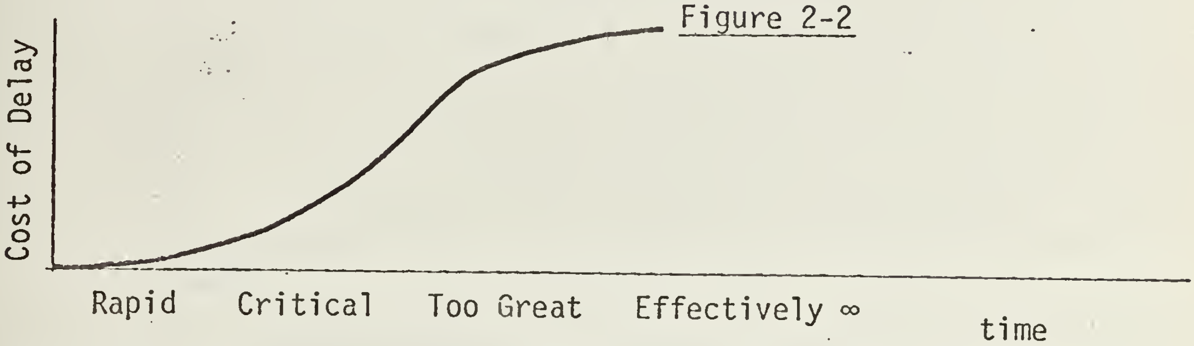


Figure 2-1 Intuitive Initial Conditions Necessary for Preemption

becomes too great and the relative increase in cost for each additional period of response time decreases. Eventually the cost does not increase anymore. This curve may be seen below.

Figure 2-2



A similar curve would exist for a nonurgent caller, although the slopes may not be as great and the total cost will not be as large.

For a first approximation, however, we will assume that the curves are linear. This will ease conceptualization of the tradeoffs that will be discussed, and it greatly simplifies computations because linear relationships are very convenient.

Now we might consider these cost curves in a preemptive context. We will define C_1 to be the cost associated with arriving at a priority one caller from the distance equivalent of a specific time. This will maintain the spatial context. C_2 will be defined analogously for the priority two caller, but it must be modified slightly to correspond to the cost associated with the replacement distance to the preempted priority two customer. These linear curves can be seen in Figure 2-3a.

To truly reflect mechanism of preempting, however, a slight additional modification is necessary. Regardless of the replacement distance to the nonurgent preempted customer, there is an inconvenience associated with preemption. That raises the "cost" of answering all preempted

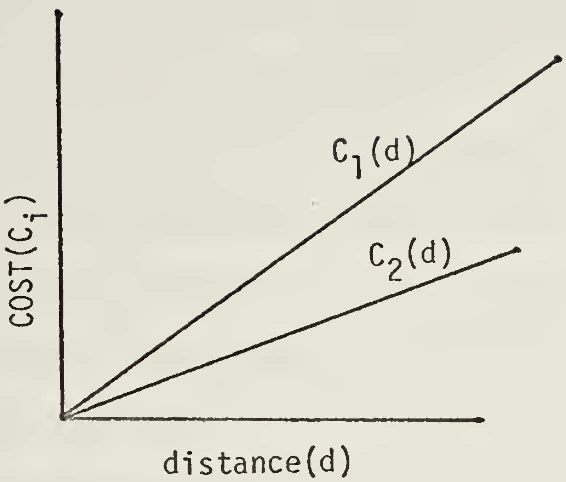


Figure 2-3a Linear Approximation of a Decision Maker's COST Curves for Urgent and Non-urgent Calls

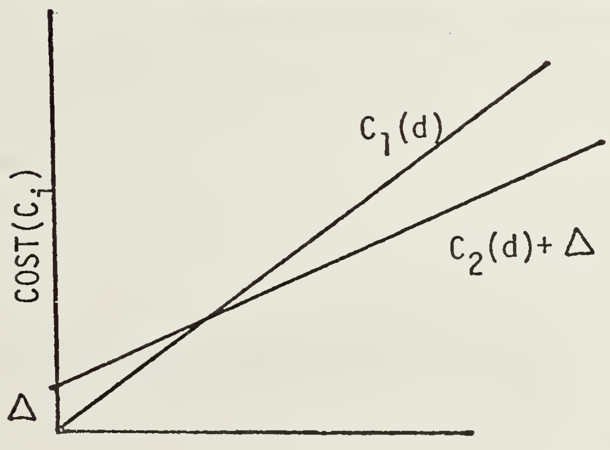


Figure 2-3b Linear Approximation of a Decision Maker's COST Curves for Urgent and Non-urgent Calls Including the Cost of Inconvenience

nonurgent callers. The degree of inconvenience will certainly vary with the amount of time the customer must wait for the replacement service, but at this stage let us account only for the constant inconvenience that will occur no matter how short a wait is experienced and call it delta (Δ). C_1 and the twice modified C_2 now appear in Figure 2-3b. A means now exists to define a "preemptable situation."

To preempt implies that (1) the closest busy nonurgent customer's unit is being dispatched to the urgent caller, and (2) a replacement unit is being sent to continue service to the preempted customer. The model has been defined as a function of the position of closest free and busy units, at this point, for conceptual convenience.

We will define the cost of preemption (C_p) to be equal to $C_1(D_b)$ + $C_2(D_r)$. This will be compared to the cost of dispatching the closest free unit (C_f) which is defined to be $C_1(D_f)$. Logically, according to these criteria, if $C_p < C_f$ we should preempt.

Thus, because the dispatcher would know D_b and D_f, we can solve the relationships for D_r, which represents the maximum preemptable radius, about the priority two unit's position, from within which the replacement unit can come.

$$D_r \leq C_2^{-1}(C_1(D_f - D_b))$$

However, just because D_r exists does not mean that preemption can occur. The spatial construction of the model must be recalled. D_f is the distance to the closest free unit. This means no free units can be located closer than a radius equal to D_f about the incoming call. Consequently,

any portion of the area associated with the arc D_r which lies within the circle of radius D_f will not have any free units within it. If the entire arc D_r falls within the arc D_f, there can be no free units and preemption cannot occur.

The critical separation between D_b and D_f that determines whether a "preemptablearea" exists, is easily determined using Figure 2-4. If the point of intersection of $C_1(d)$ and $C_2(d)$ is called D_c and $D_r > D_c$, then $C_2^{-1}(C_1(D_f-D_b)) > (D_f - D_b)$ and a "preemptable area" exists. If $D_r < D_c$, $C_2^{-1}(C_1(D_f - D_b)) < (D_f - D_b)$ and a preemptable area cannot exist. A preemptable area (A_p) will be defined to be the area beyond the circle of radius D_f but inside the circle of radius D_r, where free units are eligible to be selected as replacements. (See Figure 2-5.)

Thus a means exists to define preemption and to determine whether a preemptable situation exists. The model is based on the importance of responding to urgent and nonurgent calls at a certain time and recognizes the inherent inconvenience that is associated with preemption. A police administrator could easily provide these measures to set up the preemptivemodel. Subsequent evaluation of the model will verify the feasibility of his strategy.

E. Preemptive Dispatching Strategy

A preemptive dispatching strategy that might logically follow using this model is:

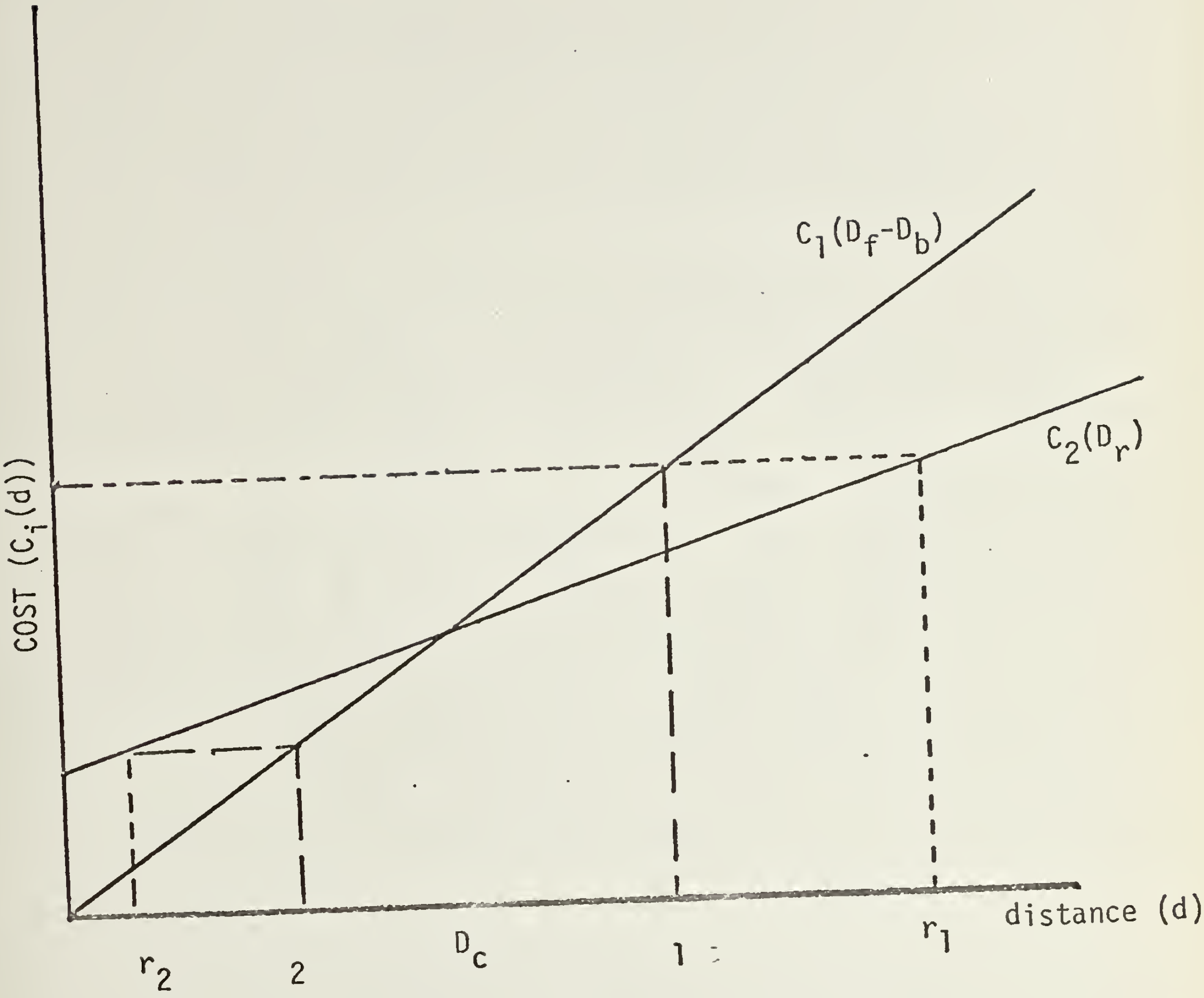


Figure 2-4 Criteria for the Existence of a Preemptable Area

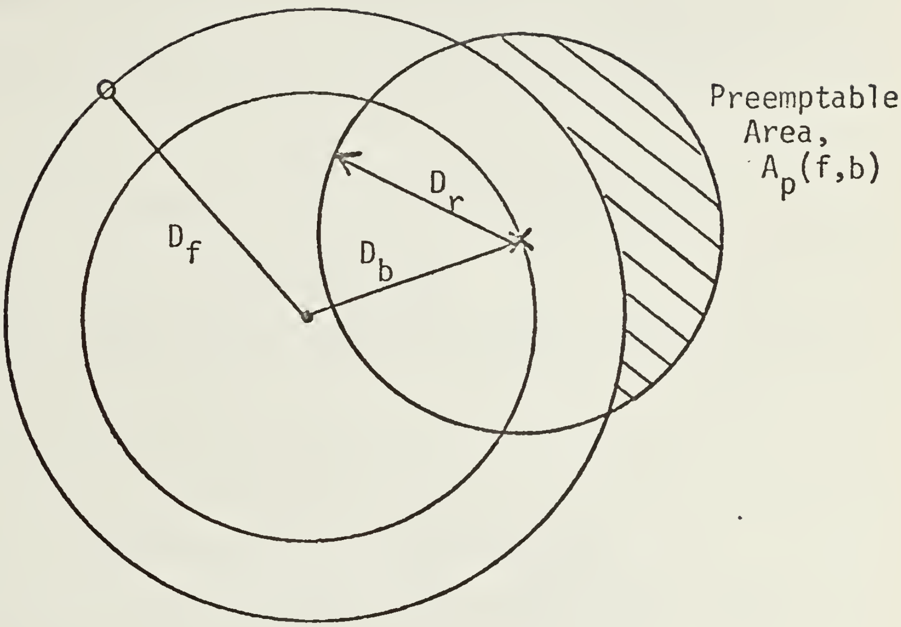


Figure 2-5 Spatial Description of a Preemptable Area

(1) Upon receipt of a nonurgent call:

(a) Dispatch the closest free unit

(2) Upon recept of an urgent call:

(a) If the closest unit is an urgent busy unit, continue searching.

(b) If the closest unit is free, dispatch the free unit.

(c) If the closest unit is a nonurgent busy unit,

(i) call that distance D_b

(ii) establish distance to closest free unit, call it D_f

(iii) determine $D_r \equiv C_2^{-1}(C_1(D_f-D_b))$

(iv) if the preemptable area exists and a free unit is in it , preempt.

(v) if the preemtable area does not exist or there is no free unit in the preemptable area, send the closest free unit to the call.

In summary, if there is an urgent call and $D_f > D_b$ such that the preemptable area exists, and there is a free unit in the preemptable area, then preemption can occur.

F. Extension

Although $D_f - D_b > D_c$, such that a preemptable area exists, there may be busy units other than the closest busy unit that satisfy $C_p < C_f$. This is because the selection criterion is a function of D_f.

This feature provides extra flexibility. Now, in a given situation, there may be more than one busy nonurgent unit that can be used for preemption to improve police effectiveness. However, it is important to investigate the implications of considering other than the closest busy unit as replacements.

The primary concern would be that the model might be biased in favor of the busy nonurgent units that are located closer to the closest free unit. This could occur if the preemptable area associated with a unit'sposition increased as the busy nonurgent unit's position got nearer to the closest free unit. If this occurred there would be a great probability of a free unit being found in the larger area.

But, this is not the case. (See Figure 2-4.) With D_f fixed as (D_f-D_b) approaches D_c, D_r also decreases. Thus the preemptable area will not grow indefinitely. Consequently the model is not based in favor of busy nonurgent units that are located closer to the closest unit.

G. Derivation of Performance Measures

Before evaluating any measures that can be derived from the model, it is important to recognize that the preemptable area is a function of

D_f and D_b not $(D_f - D_b)$. This can be illustrated in Figure 2-6. Although the separation between the respective busy nonurgent unit and closest free unit is the same in each, which implies that D_r is the same in each case, the preemptable areas must be different because that portion of the areas that is formed by the circles of radius D_{f_1}, D_{f_2} respectively are different.

G.1 Euclidean

Now it is possible to evaluate some of the measures the spatial model was constructed to define. The first probability of interest is the probability that there is a free unit in the preemptable area. Because we have assumed free units are distributed in a spatially Poisson manner, this is simply equal to

1 - Probability there are no free units in the preemptable area which is equal to $1 - e^{-\gamma Ap}$

where γ is defined to be the number of free customers per unit area

It is also possible to derive the probability density function of the distance to the closest free (or busy) unit.

Although an administrator is not likely to station free units in a completely random manner, the spatial Poisson assumptions permit us to arrive at a measure that bounds system performance.

If we assume that a call is generated at some arbitrary location,

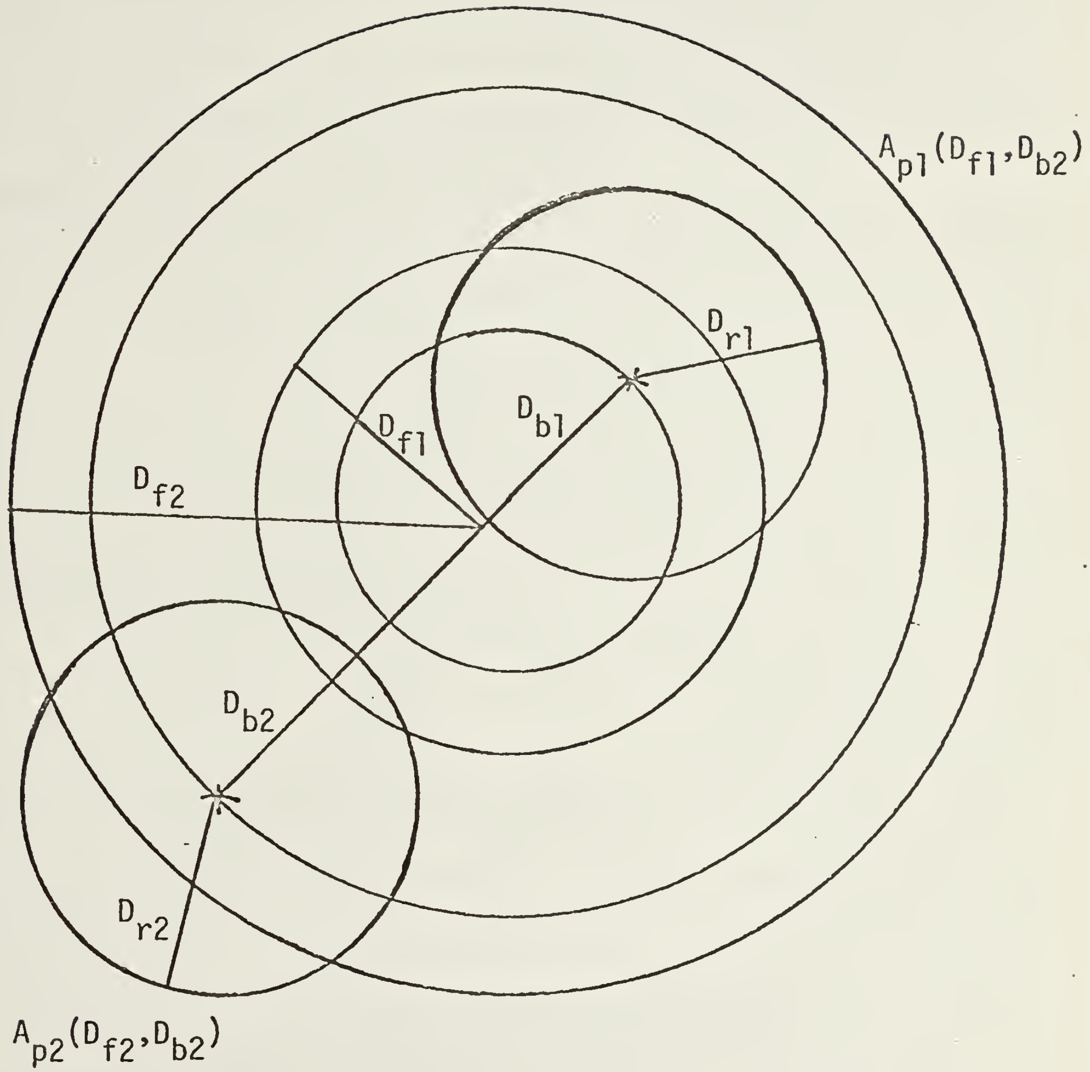


Figure 2-6 Preemptable Area as a Function of D_f and D_b not $(D_f - D_b)$

(x,y), and want to know the probability that there are K free units within the circle is

$$P\ [X(\text{circle}) = K] = \frac{(\gamma\pi d^2)^K\ e^{-\gamma\pi d^2}}{K!} \qquad K = 0,1,2,\ldots.$$

Therefore we obtain the cumulative distribution function by the following reasoning:

$$\begin{aligned} F_C(d) &= P\ [D \le d] = 1 - P\ [D > d] \\ &= 1 - P\ [X(\text{circle}) = 0] \\ &= 1 - e^{-\gamma\pi d^2} \quad (d \ge 0) \end{aligned}$$

The probability density function is

$$f_D(d) = \frac{d\ F_D(d)}{d(d)} = 2d\gamma\pi\ e^{-\gamma\pi d^2}, \quad d \ge 0$$

A Raleigh distribution

A similar proof is applicable for the distance to the closest busy nonurgent unit. $f_B(b) = 2b\rho_2\pi . e^{-\rho_2\pi b^2}$, $b \ge 0$. Intuitively, this result may be seen as

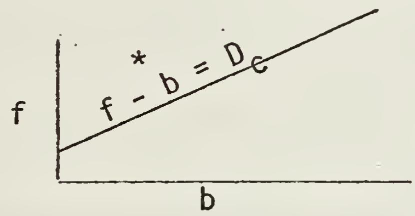
$$\begin{aligned} &P\ (0 \text{ busy} < b) \cdot P\ (1 \text{ busy between } b \text{ and } b+db) \\ &= 2\pi b\ \rho_2\ e^{-\rho_2\pi b^2} \cdot e^{-\rho_2\pi b^2} \cdot 1 \quad \text{as } db \to 0 \end{aligned}$$

Another measure of interest is the probability that preemption

will occur in any given situation. Intuitively, the probability preemption occurs equals

P [preemption occurs]= P [preemptable area exists and a free unit is in that preemptable area]

Looking at a distribution of the spatial relationships between nonurgent busy units and free units,



a preemptable area will exist as long as $f-b \geq D_c$. The probability a preemptable area exists can then be computed by,

$$P(A_p) = \int_{f=D_c}^{\infty} \int_{b=0}^{b\equiv f-D_c} 2f\rho_f \; e^{-\rho_f \pi f^2} \cdot b\rho_b \; e^{-\pi\rho_f b^2} dbdf$$

but this equation is not analytically tractible unless an interactive computer program is created to evaluate the integral. Another means must be devised to evaluate this important measure.

G.2 Performance Measures in Right Angle Distance Metric

Now that the model is understood it will be converted to more applicable right angle distance metric. The axis will run parallel to the city's street grid network (unsymmetric cities can be

be described with appropriate approximations).

The following locations are defined:

$(x_c, y_c) \equiv$ location of incoming pri 1 call

$(x_b, y_b) \equiv$ location of busy pri 2 unit

$(x_f, y_f) \equiv$ location of closest free unit

(For convenience in many of the calculations I will assume $(x_c, y_c) = (0,0)$. It will be obvious in the context of the situation)

Elementary computations will demonstrate that an equidistant perimeter about an incoming call will be a square rotated 45^0 counter clockwise such that the corners are on the x and y axes. (See Figure 2-7.)

Using geometry we can determine the following values and relations:

1. $b = \sqrt{(x_c - x_b)^2 + (y_c - y_b)^2}$
2. $f = \sqrt{(x_c - x_f)^2 + (y_c - y_f)^2}$

Let $A_q x + B_q y + C = 0$ be the equation of any line (*)

3. $A_q x + B_q y + b = 0$ is the equation for each side of the b perimeter.
4. $A_q x + B_q y + f = 0$ is the equation for each side of the f perimeter.
5. $A_q(x - xb) + B_q(y - yb) + r = 0$ is the equation for each side of the r perimeter about (xb,yb).

The preemptable picture using the rectangular metric is found in Figure 2-7. We now need a method to compute the preemptable area.

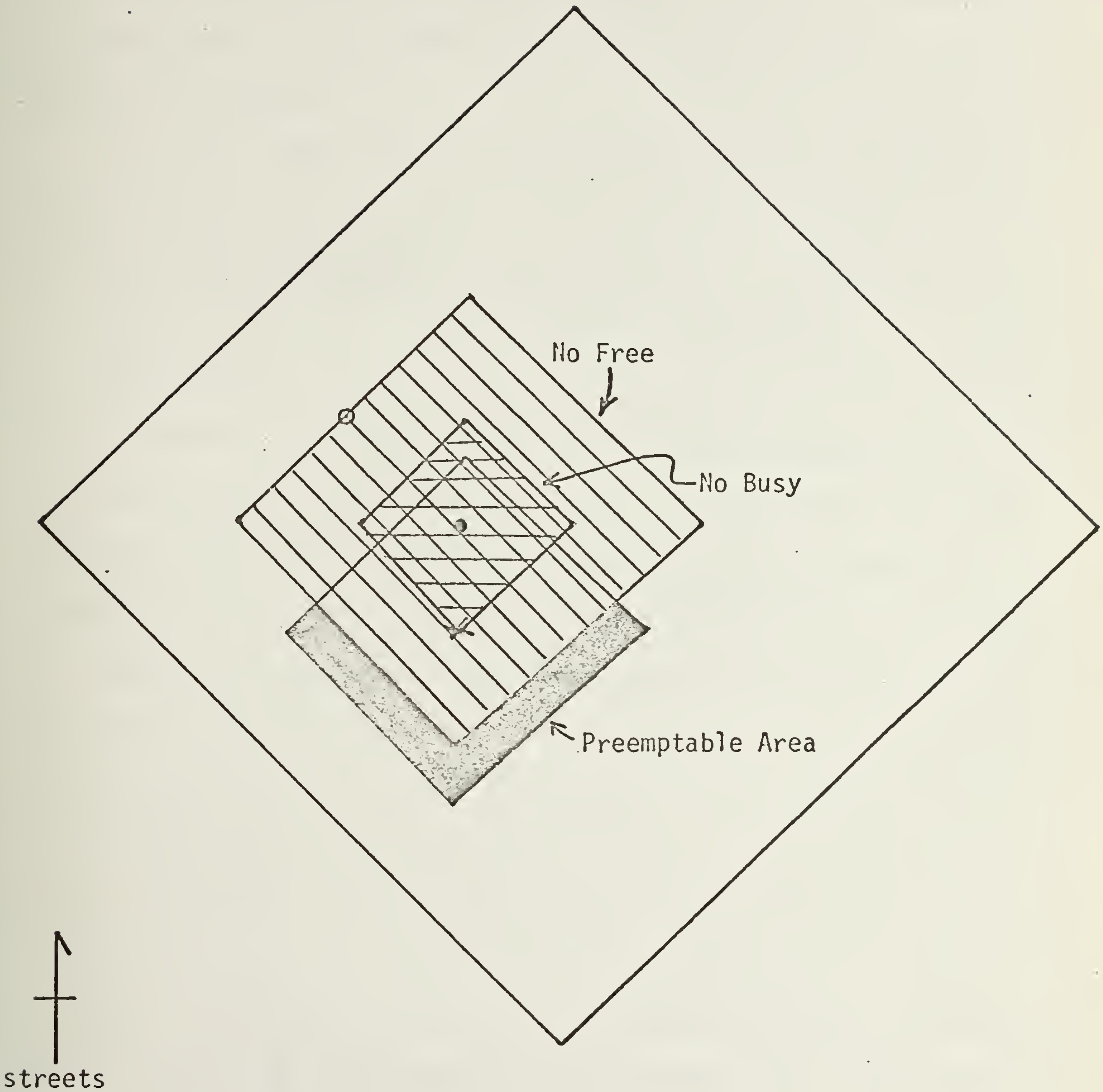


Figure 2-7 Preemptable Area in Right Angle Distance Metric

$A_p(f,b)$ in Figure 2-7 is the area within that portion of the r perimeter which extends beyond the f perimeter. We can imagine $A_p(f,b)$ being formed by a series of overlapping rectangular areas. $A_p(f,b)$ is equal to the sum of the rectangular areas corresponding to the four sides of the perimeter minus any intersecting areas that were double counted.

It is well known that the perpendicular distance from a point to a line is

$P_{k,g}$ (the perpendicular distance from point (x_1,y_1) to line L) $\equiv$

$$\frac{A_q x + B_q x + C_k}{\sqrt{A_q{}^2 + B_q{}^2}}$$ where a line L is described

by the equation $A_q x + B_q y + C = 0$ and q designates the quadrant that is in question.[45] For convenience, I will designate the point from which all perpendicular distances are measured (x_b,y_b) because in general all distances of interest are measured from the busy nonurgent unit location. k may equal f,b,r, or t (t is to be defined later). The following relationships are defined

$$C_f \equiv D_f$$

$$C_b \equiv D_b$$

$$C_r \equiv D_r$$

$$C_t \equiv D_t$$

Finally, q corresponds to the quadrant in which the line of interest is located. A_q and B_q will always be (± 1) depending on q. The appropriate values can be found in Figure 2-8.

Figure 2-8

Quadrant Designation

q = IV	q = I
A = -1	A = 1
B = 1	B = 1
q = III	q = II
A = -1	A = 1
B = -1	B = -1

In general the distances of interest are from (Xb, yb) such that

$$P_{f,q} = \frac{A_q x_b + B_q y_b + \sqrt{(x_c - x_f)^2 + (y_c - y_f)^2}}{\sqrt{A_q^2 + B_q^2}} = \frac{A_q x_b + B_q y_b + D_f}{\sqrt{2}}$$

$$P_{r,q} = \frac{A_q x_b + B_q y_b - A_q x_b - B_q y_b + C_2^{-1}(C_1(D_f - D_b))}{\sqrt{A_q^2 + B_q^2}} = \frac{C_2^{-1}(C_1(D_f - D_b))}{\sqrt{2}}$$

For further notational convenience we will designate the following for the respective "distance differences".

$$D_{r,q} \equiv P_{r,q} - P_{f,q}$$

$$D_{t,q} \equiv P_{t,q} - P_{f,q}$$

The following decision rule now applies:

(1) if $D_{r,q} < 0$ set $D_{r,q} = 0$

if $D_{r,q} > 0$ set $D_{r,q} = D_{r,q}$

Intuitively, these "distance differences" measure how far the r perimeter extends beyond the f perimeter on each side. If consecutive sides each protrude, the intersecting area must be subtracted from the sum of all overlapping areas.

Perhaps an example would be helpful (see Figure 2-9). In quadrant I $P_{r,I} > P_{f,I}$ so that $D_{r,I} > 0$. Thus an area component of A_p (f,b) exists from quadrant I. However in quadrant III $P_{r,III} < P_{f,III}$ so that $D_{r,III} < 0$. No area exists in quadrant III.

The total preemptable area A_p (f,b) ≡

$$\sum_{q=I}^{IV} D_{r,q} \cdot \sqrt{2}\, P_{r,q} + \Sigma D_{(r,q)} \cdot D_{(r,q+1)}$$ for (q,q+1) equal to

(I,II), (II,III), (III,IV), (IV,I).

At this point, we are nearly ready to use the model to evaluate applicable performance measures in a right angle distance metric. First however, it is important to note and resolve a complication that has arisen on switching to a right angle distance metric.

As Figure 2-10 demonstrates, the preemptable area is now a function of D_f, D_b and x_b - the position of the busy unit. As the position of the busy unit changes around the b perimeter so does the preemptable area, A_p (f,b,$\underline{x_b}$)

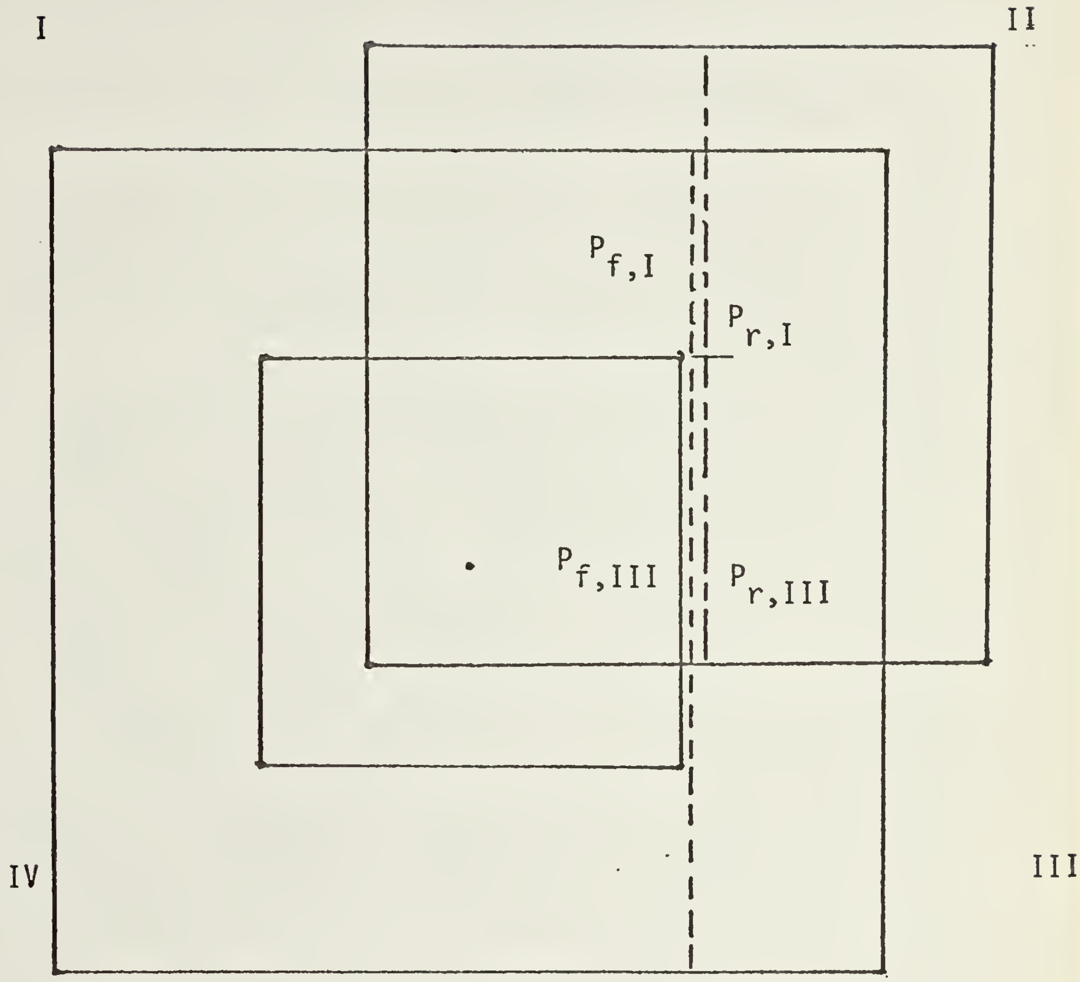
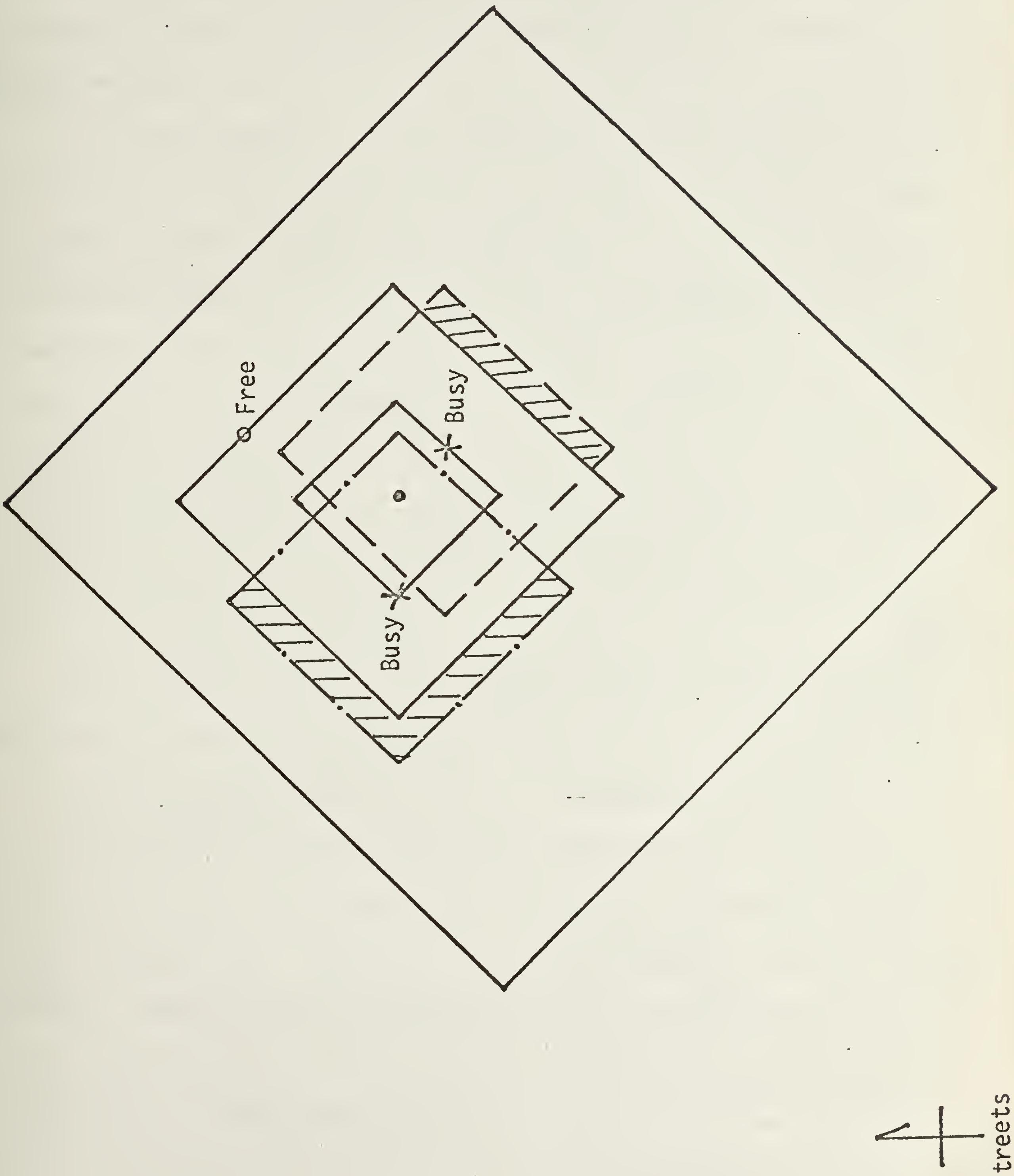


Figure 2-9 Preemptable Area- A Sum of Overlapping Areas

Figure 2-10 Preemptable Area in a Right Angle Distance Metric - A Function of the Busy Unit's Postion



Thus, if we want to determine the probability that there is at least one free unit in the preemptable area, the probability must be evaluated for each x and then each probability must be weighted approximately.

Due to the symmetry of the problem it is necessary only to evaluate values of x_b along one edge. The length of one edge of the b perimeter is $\sqrt{2}\, b$. If it is assumed that busy units are uniformly distributed along that, or any, edge, then the probability (of selecting any particular X_b between 0 and b) = $\frac{1}{\sqrt{2}\, b}\, dx$.
Intergrating over all X implies

$$P[\geq 1\text{free unit in } A_p(f,b)] = \int_0^b \frac{1}{\sqrt{2}\, b} \cdot P[\geq 1\text{free in } A_p(f,b,x_b) \mid x_b]\, dx$$

where $P[\geq 1\text{free in } A_p(f,b,x)] = 1 - e^{-\gamma A_p(f,b,x)}$ and $A_p(f,b,x)$ is as defined.

One performance measure of interest is the mean travel distance. Specifically there are two mean travel distances:

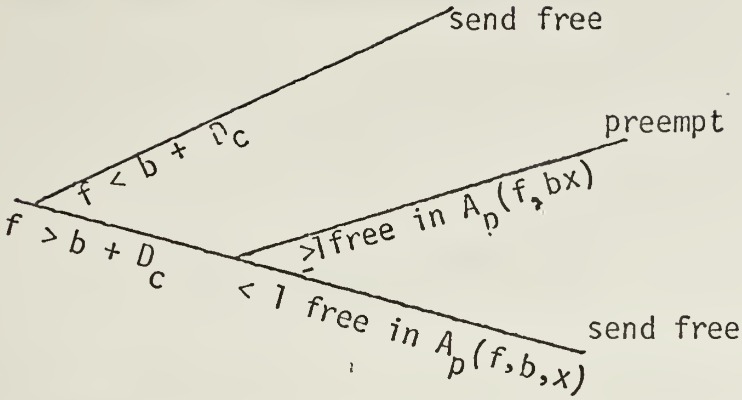
(1) the mean distance to the pri 1 incident

(2) the mean distance to the pri 2 incident.

In each case, it is theoretically possible to dispatch any unit to any incident within the city. There is no attempt to maintain sector identity. That is, there is no effort to keep a unit within the specific sector he is usually assigned to patrol.

The spatial conditions that must be met are described on the tree

below:



A preemptive dispatching strategy allows two choices:

(1) preempt

(2) don't preempt

The distance to the closest free (or busy) units are easily derived.

$$f_f(f_0) = 4\gamma f_0 e^{-2\gamma f_0^2} \qquad f_b(b_0) = 4\rho_2 b e^{-2\rho_2 b_0^2}$$

The analysis used is the same as in Euclidean distances, except instead of a circle of radius d there is a square rotated 45^0 to the axis with area $2d^2$.

Thus we are looking for the mean travel distance for each of the three branches above.

Preemption will occur if (1) the closest busy is at D_b, (2) the closest free is at D_f, (3) $f > b + dc$, and (4) there is at least 1 free in $A_p(f,b,x)$. Thus

$$E(b) = \int_{b=0}^{\infty} \int_{f=b+dc}^{\infty} b\left(\int_0^W \frac{1}{\sqrt{2}\, b} \left(1 - e^{-\gamma A_p(f,b,x)}\right) dx\right) \cdot$$

$$4\rho_2 b e^{-2\rho_2 b^2} \cdot 4\gamma f e^{-2\gamma f^2} df db$$

There are two situations when a free unit is dispatched:

(1) $f < b + D_c$

(2) $f > b + D_c$ but there is no replacement.

$$E(f_{(1)}) = \int_{f=0}^{\infty} \int_{b=f-d_c}^{\infty} f \cdot 4\rho_2 b e^{-2\rho_2 b^2} \cdot 4\gamma f e^{-2\gamma f^2}\, db\, df$$

$$E(f_{(2)}) = \int_{b=0}^{\infty} \int_{f=b+d_c}^{\infty} f \cdot \left(\int_0^W \frac{1}{\sqrt{2}\, b} \cdot \left(e^{-\gamma A_p(f,b,x)}\right) dx \right) \cdot$$

$$4\rho_2 b e^{-2\rho_2 b^2} \cdot 4\gamma f e^{-2\gamma f^2}\, df\, db$$

Next, we will derive the mean travel distance to the pri 2 customer. It will be assumed that we will always dispatch the closest free unit. The method used will derive the mean travel distance from the CDF of the travel distance to the closest free replacement unit. The free unit must be in A_p (f,b,x). Call the distance to the closest free unit in the preemptable area t. Associated with t is a preemptable are A_t (f, b, x, t)

$$P_{T\leq}(t) = 1 - P_{T\geq}(t)$$

but $P_{T>}(t) \equiv P[\text{no free units} \leq t] = e^{-\gamma A_t(f,b,x,t)}$

$$P_{T\leq}(t) = 1 - e^{-\gamma A_t(f,b,x,t)}$$

The pdf of travel distance is equal to the derivative of the CDF with respect to t.

It only remains to find the probability of no free units being < t units to (x_b, y_b). This is dependent on $A_p(f,b,x)$. If t does not

fall in A_p- or t exceeds r, then no one can be sent as a replacement. The P [closest free unit = t] = 0 in this case.

Consequently, $P_{t,q}$, $D_{r,t,q}$, $A_t(f,b,x)$ are are defined below. The notation is the same that was used before.

$P_{t,q} \equiv$ Perpendicular distance from the busy nonurgent unit to the t-perimeter, where t is a variable

Thus, $P_{t,q} = t/\sqrt{2}$

$$D_{r,t,q} \equiv P_{r,q} - P_{t,q}$$

$$D_{t,q} \equiv P_{t,q} - P_{f,q}$$

The following decision rules are needed to compute the preemptable area with respect to variable t.

(1) If $D_{t,q} < 0$, then set $D_{t,q} < 0$

(2) If $D_{t,q} > 0$ then set $D_{t,q} = D_{t,q}$

(3) If $D_{r,t,q} < 0$, set $D_{r,t,q} = 0$

If $D_{r,t,q} > 0$ this implies

$$A_t = \sum_{q=I}^{IV} D_{t,q} \cdot \sqrt{2}\, P_{t,q} - \Sigma\, D_{t,q} \cdot D_{t,q+1} \quad \text{where } q,q+1 \text{ are}$$

(I,II), (II,III), (III,IV), (IV,I)

If $D_{r,t,q} < 0$, $A_t = 0$ because t is everywhere beyond the D_r perimeter, so no unit can be dispatched from within the allowable area.

This implies

If $D_{r,t,q} > 0$, $A_t = \sum_{q=I}^{IV} D_{t,q} \cdot \sqrt{2}\, P_{t,q} - \Sigma\, D_{t,q} \cdot D_{t,q+1}$ where q,q+1 are defined as above

if $D_{r,t,q} < 0$, $A_t = 0$ because t is everywhere beyond the D_r perimeter, so no unit can be dispatched from within the allowable area.

Now, knowing the CDF of travel distance to the closest replacement unit, the mean distance to a replacement unit can be computed.

H. Conclusion

Thus we have shown that a set of curves which reflect the costs incurred for each additionan minute of delay in arriving at an incident can be used to define the spatial constraints of a preemptive despatching strategy. If a spatially oriented M/G/∞ service system is assumed to be an appropriate approximation of reality, then performance measures can be derived that provide valuable insight into the effects of preemption, and allow preemption to be compared to other dispatching strategies.

III. DECISION THEORY

A. Introduction

Any decision problem under uncertainty must deal with two sources of complexity: (1) multiple objectives and (2) uncertainty. Police dispatching certainly involves both of these considerations.

There are four steps that must be completed to solve such a problem using a Decision Analysis approach:

(1) structure the problem

(2) quantify uncertainties

(3) quantify preferences

(4) evaluate alternatives.

Steps (1) and (2) are developed into a decision tree.
Steps (1) and (3) create a multiattribute activity function. Point (4) represents the final evaluation of the model that is created.

B. Decision Theory - Background

The evaluation of a preemptive dispatching strategy is a complex, probabilistic decision problem which entails the manipulation of many consequences. The mathematical model that has been presented provides a means to conceptualize preemption and objectively measure some of its effects. Utility theory allows the construction of a simple multiattribute utility function that incorporates the subjective and objective feelings

of both the server and customer. A means is needed to correlate events, their probabilities, and their outcomes. The structure must reflect the dispatching process and require no more information than is presently available.

Decision Theory emerged from the need to systematically evaluate decision problems under uncertainty. It allows the decision maker (d.m.) to organize his opinions in an acceptable framework that will allow him to make consistent evaluations considering all pertinent information. It incorporates utility theory and probability theory to reflect a d.m.'s personal judgement and experience.

The advantages of decision theory are (1) decisions will be consistent with the d.m.'s judgement and preferences, (2) the decision process is well defined, (3) it helps a d.m. anticipate conditions with which the dispatching strategy might have to contend, and the possible consequences of the actions that are taken, (4) the structure will improve the dispatcher's effectiveness by keeping track of the routine, predictable aspects of dispatching, allowing the dispatcher to focus his attention on the unusual nature of a particular incident.

C. Setting of the Analysis - an Emphasis of Crime

Crime related calls comprise only 20% of the police force workload. The other 80% of their work is related to public services of one sort or another. Consequently, a preemptive dispatching strategy, using current

prioritization criteria, would be used to improve service to crime as well as non-crime related calls. In fact, in the introduction to this paper it was suggested that the criteria that are used to define a call's urgency be broadened so that other calls, whether they are crime or non-crime related, might benefit by preemption. It is suggested that preemption could be most effectively employed in this manner.

There are many instances that are intuitive candidates to be treated as urgent calls under this new criterion. There are many "in progress" or "suspect on the scene" type calls or other special situations where one can imagine that especially rapid response would be welcomed.

However, the means to evaluate the circumstances that could key dispatching personnel that such service is needed requires much study. Situations that "might" become worse and thus could benefit from initial rapid response must be probablistically evaluated to verify the usefulness of considering them urgent. At this stage a comprehensive list of such incidents would be quite difficult to compile. Now, only a few non-crime related calls are handled in an urgent manner. Experience has shown that incidents such as family quarrels and civil disputes often escalate and warrant early rapid attention. It is not unreasonable to assume further study will disclose even more instances when this consideration would be warranted.

Thus, it is clear that preemption, even under current prioritization criteria, can be used to provide better service for crime and non-crime

related calls. However, to simplify our discussion in this paper we will emphasize and evaluate the impact of preemption primarily on crime related incidents.

There are a number of reasons why emphasizing crime may even be beneficial: (1) when the public is asked to evaluate the value of police response to non-crime related calls, the number of new situations which would now be considered urgent, might prove to be confusing to evaluate because the situation that is being investigated is new and unfamiliar. (2) It is not clear that it is unreasonable (see chapter nine for more discussion on problems of prioritization of calls) to assume that the projected success of preemption on non-crime - or new, urgent - calls will be any worse than with crime related calls. (3) In fact, the effectiveness of preemption with respect to non-crime versus crime related calls may be better because calls for service such as settling an argument, may only require police presence and direction to prevent further escalation of an incident, or to deter further progression of an act that may develop into a crime. In the special case where the police may be answering a non-criminal emergency call for service, such as aiding a person who has fainted, police effectiveness in the eyes of the customer and the public automatically increases because he is there. He is not expected to apprehend a criminal before his presence is greatly appreciated. (4) Similarly emphasizing non-urgent crimes should not bias the customer in favor of a preemptive dispatching strategy, because an unsatisfactory

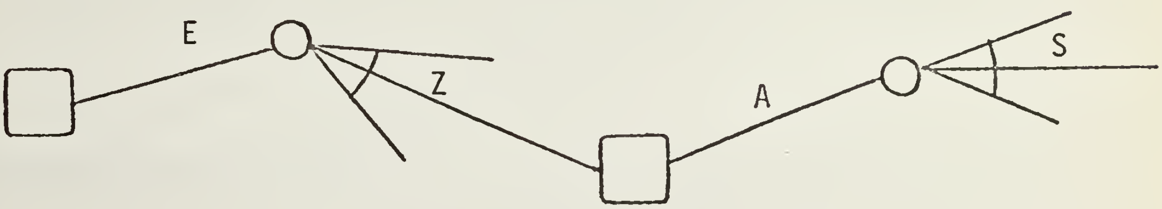
experience as a result of preemption crimes is probably just as likely when nonurgent incidents are emphasized, as when they are represented in their true proportion of occurrence.

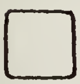
It is recognized that emphasizing the effects of preemption on crime related incidents omits an important category of situations that will certainly benefit from preemption. But this assumption should facilitate understanding preemptive dispatching and eliminate confusing and unnecessary detail without distorting the model's validity.

D. Decision Trees

D.1 Introduction

Decision Analysis is based on four basic postulates (see von Neumann and Morganstern).[46] Possible outcomes at any stage are described in terms of "canonical lotteries". A diagram of a particular decision process forms a tree which details all possible outcomes of the process. A very basic tree is:[47]



where  is a decision point

and  represents a probabilistic outcome.

A person decides to take an experiment (E). As a result of the experiment there are a number of probabilistic outcomes (Z). Based on the outcomes (Z), the d.m. takes action (A), which results in a number of probabilistic states of nature(S). The probability of any specific sequence of probabilistic outcomes (Z_i, S_i) can be determined by multiplying the probabilities along each respective branch.

The decision tree for any dispatching process is necessarily complex. There is much information that is made available to the dispatcher with each new call. In addition it is the dispatcher's job to smoothly administer the workload of the patrol force. Thus he is not only concerned with customers' needs, but the patrolmen's as well. The decision tree must be capable of demonstrating how the dispatcher balances the needs of the customer, system and server. In certain situations spatial constraints must also be considered.

A preemptive dispatching process can be broken down into three sequences. Each sequence is comprised of a decision, or action, followed by at least one probabilistic state, or outcome. The three are:

(1) Answering the call

(2) Classification and evaluation

(3) Assignment and outcome.

D.2 Answering Sequence

The first action taken occurs when the complaint officer (c.o.) answers

the call. The complaint officer's task is to extract as much information from the caller as quickly as he can - as time is often critical. In general he tries to determine: (1) what the problem is, (2) where it occurred, (3) who is calling and, (under an alternate screening criterion), (4) whether or not a suspect is on-the-scene. This sequence is diagrammed in Figure 3-1.

Although this process has been depicted as simply as possible, a great deal of information can be included in the tree. For instance both the complaint officer and dispatcher develop a sense of "reliability" based on their experience, that weighs the call type, its source and its location. They are more likely to believe a report of an incident from a policeman than an anonymous caller. This bias could certainly affect future decisions, and appropriate conditional probabilities could indicate these feelings on the tree. Similarly, the type call and whether or not it is in progress will influence the evaluation of a call's urgency. Also by distinguishing between calls that are, or are not, in progress on the tree, it will permit us to evaluate the dispatching strategies under various screening criteria.

D.3 Classification Sequence

Once the information is gathered, it is passed to the despatcher via a conveyor belt or a computer terminal. (See Figure 3-2). A priority classification is assigned, often with verbal communication between the two men.

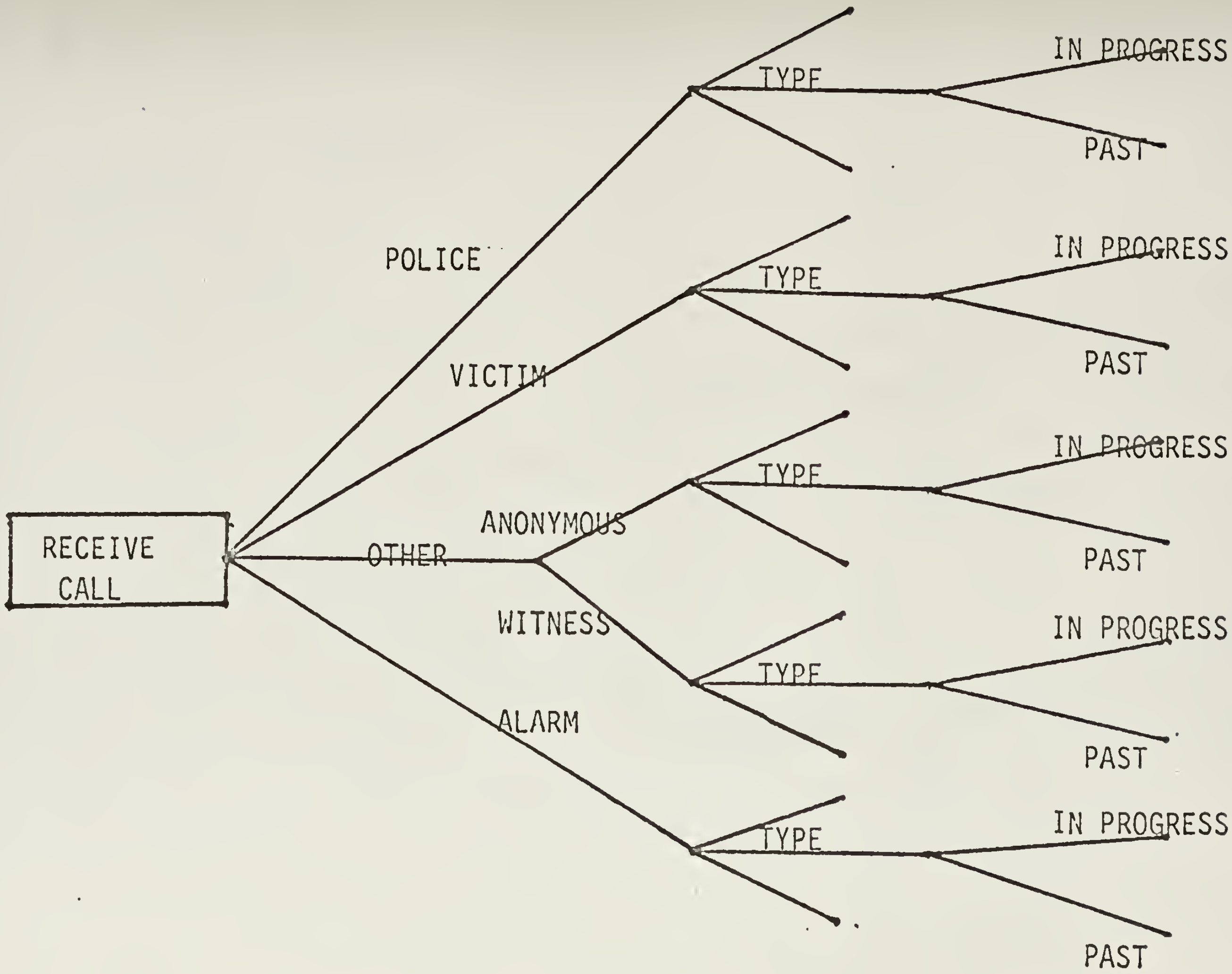


Figure 3-1 Sequence #1: Call Answering Process

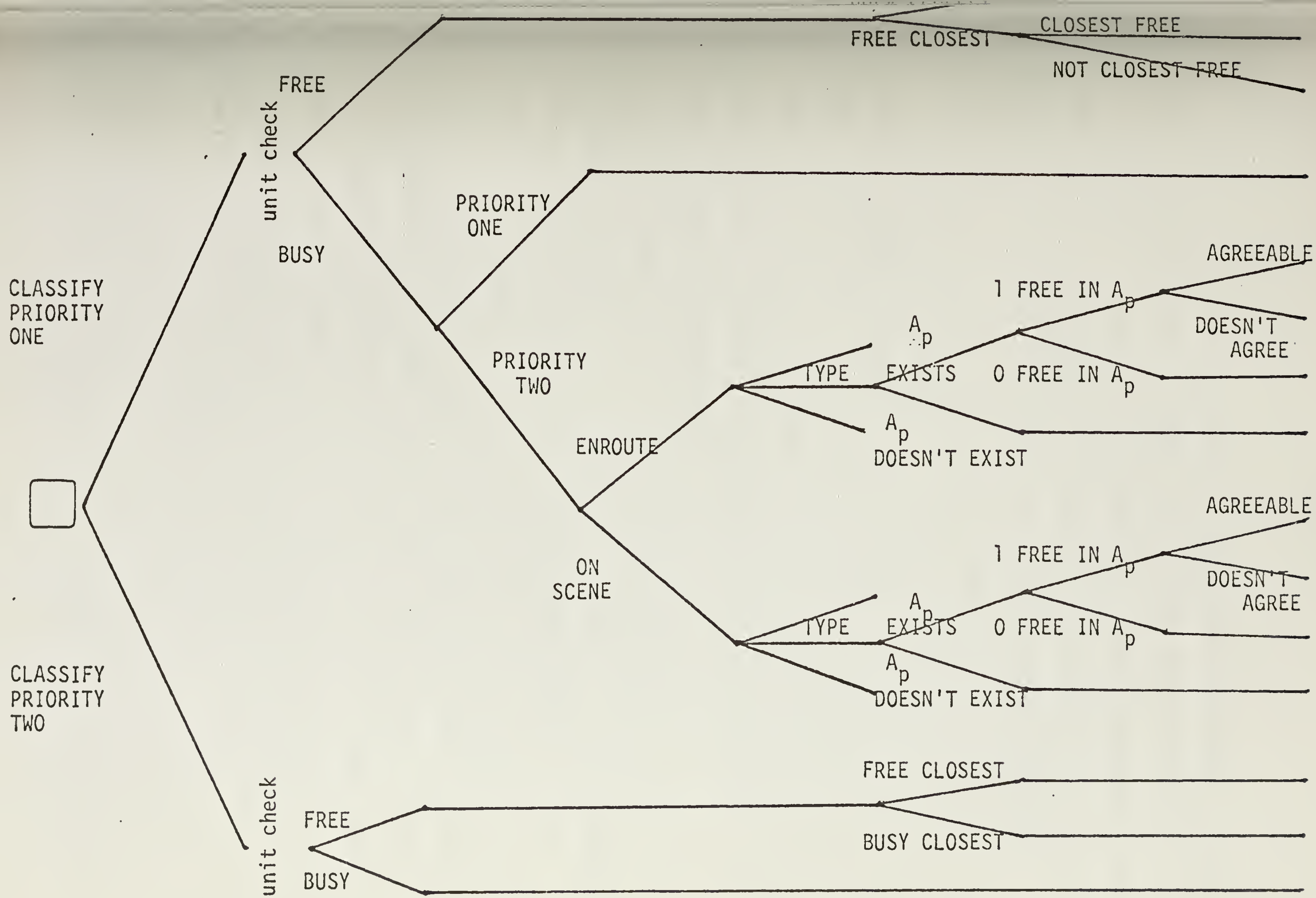


Figure 3-2 Sequence #2: Call Classification and Unit Check

At this point the dispatching process depends on the priority classification of the call. With an urgent call, besides one way streets or rivers, the dispatcher is concerned with additional, spatial constraints that define the "preemptability" of a busy unit. He must not only evaluate the utility of sending the closest free that meets the necessary requirements. The "best" unit must be chosen from this group.

Classified Priority One. As each unit is investigated, the first question is whether the unit is busy or free. If the unit is free and closer than all other units, we want to dispatch it. If it is the closest free unit we will remember its distance from the scene, because that distance is the spatial reference for the preemptive model. All other free units are disregarded.

On the other hand, if a unit is busy, has it been assigned to a priority one incident, or a priority two incident? If it is attending a priority one incident, it must be disregarded because it is not eligible for preemption. If it is servicing a nonurgent caller, it is eligible to be preempted, but it is important to determine if the unit is en route or on the scene, and then what job it has been assigned. By distinguishing between en route and on the scene, the model allows consideration of the additional error that could occur because it is not certain what type job the unit is going to service until it actually arrives on the scene.

The spatial constraints have not been checked until this stage because each of the previous events serves to filter out potential "preemptables." Waiting will reduce the number of computations that are necessary. The question of interest is, "Is there a busy unit located closer than the closest free unit such that a preemptable area exists. If $D_b < D_f - D_c$, the preemptable area exists and the unit remains eligible. Otherwise, it is disregarded.

Then, is there a replacement unit available in the preemptable area? Again, if so - continue, if not - disregard that unit.

Now that all constraints have been met does the eligible attending unit feel it is available for preemption? - Is it agreeable? This is an important consideration in the analysis, and in real life, because this deliberate query will hopefully eliminate an error that could easily result from using predetermined probabilities to decide that a job is of a nature that its service can be interrupted. Even if the dispatcher was notified on arrival of the incident's status, he cannot otherwise be sure how service is progressing. In addition, it permits the important assumption that a preemptive resume queuing discipline exists.

Preemption can be broken down into preemptive "resume" or preemptive "repeat" strategies. Under a preemptive resume strategy service to

the interrupted customer is begun where it had ended. There is no need to repeat any portion of the service that had been done before. Under the preemptive repeat strategy, however, service must be re-initiated. In fact, preemptive repeat strategies can be described mathematically as preemptive repeat with, or without, resampling.[48]

In the police context we will try to insure a preemptive resume strategy is appropriate so that little service time is wasted and the only effect of preemption will be increased travel time and possibly a queuing delay. It is not unreasonable to expect that we could approach a preemptive resume strategy if the attending unit is first asked if they feel they can leave the scene. This methodology will always allow the attending unit to assess the situation and insure it is stable so that the replacement unit will only have to provide additional counseling or check up on the situation.

Classified Priority Two. For the case in which a call is classified nonurgent, the decision process being described will be a typical "dispatch the closest free unit" strategy. Again, the dispatcher checks each unit to see whether it is busy or free. If it is busy, it is disregarded because service is not interrupted for nonurgent calls. If it is free,

but not the closest free, it is also disregarded. Only the closest free unit will be considered for dispatching.

At this stage, the dispatcher has identified the closest free unit as well as any units which meet all the requirements of "preemptability". He must decide whether to preempt or not, and the specific unit that will be dispatched. (See Figure 3-3).

If the only unit under consideration is a free unit, then the consequences of dispatching a free unit are evaluated. This is the case when the call is classified a priority 2, or there are no busy units that meet all the preemptive constraints. Otherwise, the results of either choice must be evaluated. The value, or expected utility, of each outcome will determine which is the best choice.

D.4 Unit Assignment Sequence

Once the dispatcher has decided to preempt or not preempt, the problem is no longer within his control. (See Figures 3-3,4.) When he must wait until the policeman arrives on the scene to learn the accuracy of his judgement, he finds out whether he dispatched correctly or incorrectly. For instance, if the dispatcher decided to preempt to provide service to a call that was judged to be urgent and it was an urgent call, then the dispatcher responded PROPERLY. However, if it turns out that the incident was non-

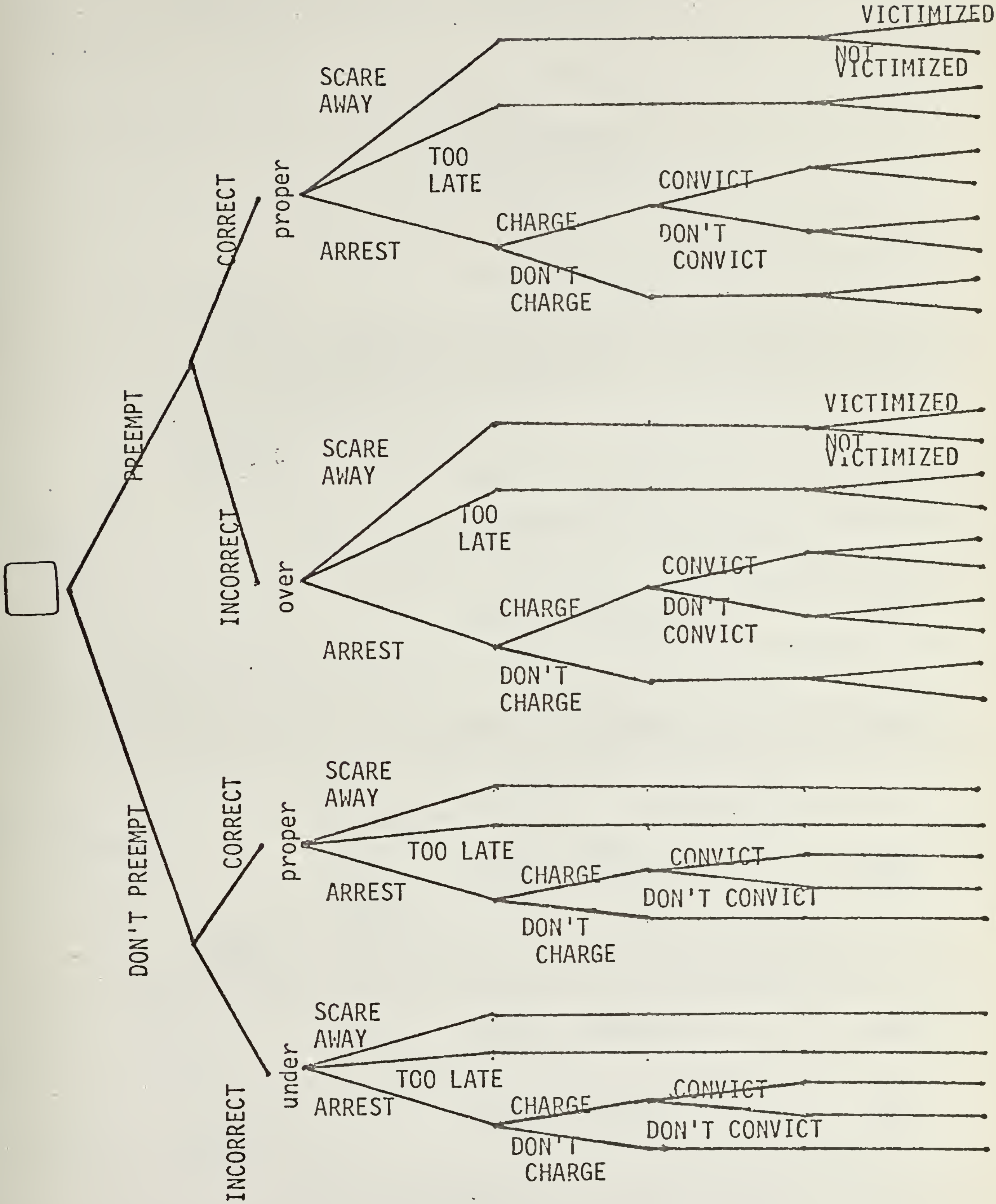
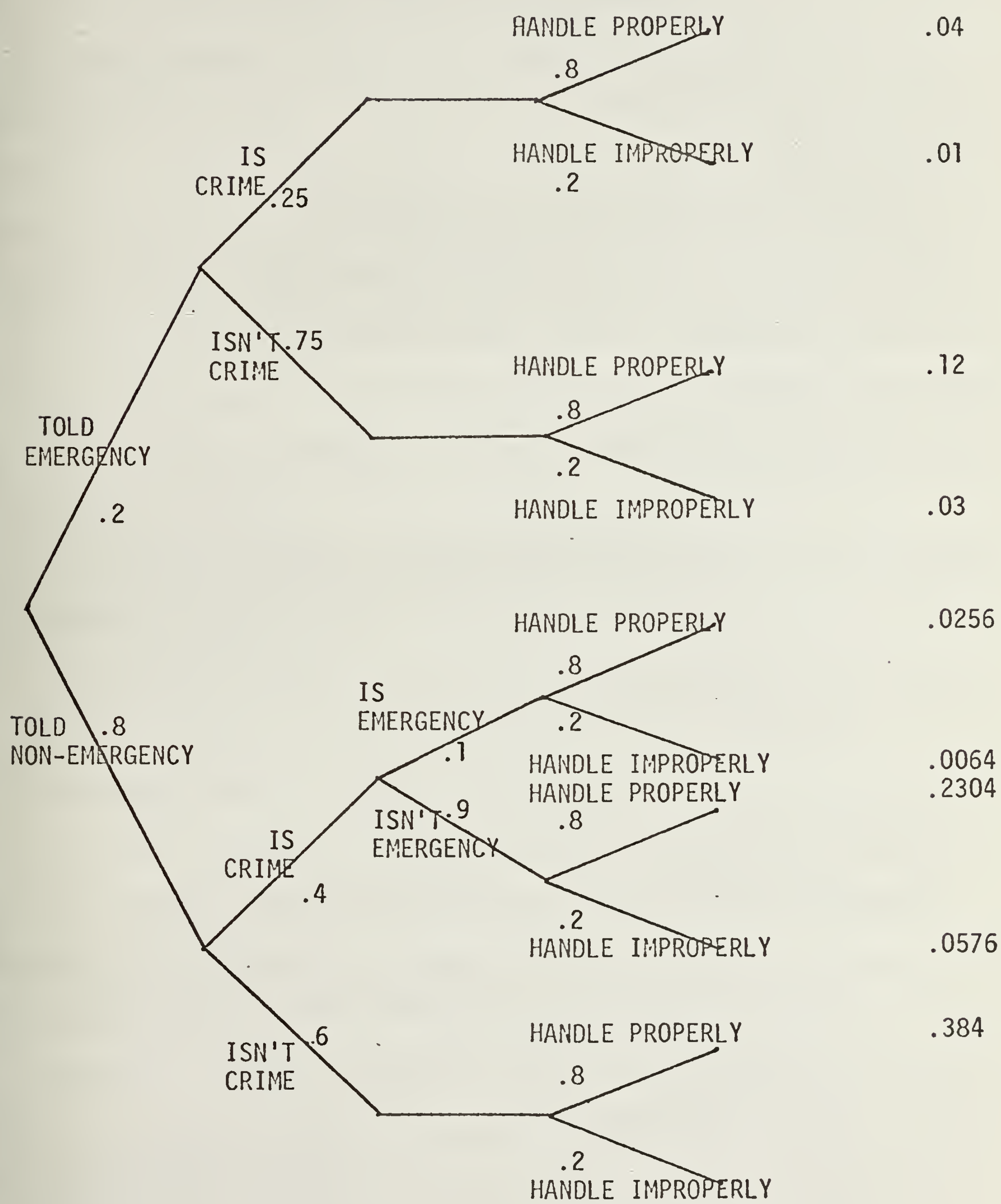


Figure 3-3 Sequence #3: Dispatching Decision and Consequences for a Preemptable Situation

Figure 3-4 Probabilistic Outcomes of Prioritization



urgent then the dispatcher OVER responded. A similar set of outcomes is possible if the dispatcher decides not to preempt.

Next the dispatcher learns of the outcome of the service given to the priority one customer. The police might arrive on the scene in time to arrest the suspect or they may only arrive in time to scare him away, or they may be too late. The dispatcher could project the chance of charging or convicting the suspect, once it is known if an arrest occurs.

The final piece of information that is known is whether or not the preempted customer was victimized while waiting for his service to be completed. If no one was preempted, of course, there is no chance of victimization.

Now the tree is complete. It describes the decision process involved with preemptive despatching and the probabilistic nature of any action.

E. Modification of Initial Tree

The decision tree as described offers a comprehensive description of a preemptive dispatching strategy. It would be reasonable to assume that if all relevant probabilities were available, an equally complete evaluation of the dispatching strategy could occur (prior to implementation). However, unfortunately much of the data that is required is not available.

In the first sequence (Figure 3-1) the data received in the phone conversation is broken down into the type of incident and the source. Police records only record the type of incident. They do not distinguish its

source. Thus information that might be used to measure reliability, or demonstrate its effect, is not available; data cannot be correlated to show that the dispatcher believes a call from a policeman more, or that the policeman is more accurate.

Also data that is concerned with the use of "in-progress" or "suspect on the scene" criteria in police dispatching is scarce. Few departments include a formal prioritization scheme. As such there is little information that could be used to connect the probability of detecting a crime in progress with the type of call or its duration.

In sequence two (Figure 3-2) the probabilities that are needed on branches that relate to constraints imposed by the spatial model can be determined analytically or by a simulation. However, the probability a unit is AGREEABLE or NOT AGREEABLE is not known, and there is no way to relate this occurrence to the type crime that is being preempted, although it is obvious some crimes are more amenable to preemption. Also there is no data available that could provide an impression of the potential error that preempting a customer en route could cause.

It is also hard to find the data that is needed for sequence three. The entire question of prioritization is a significant problem in its own right. There is very little means to evaluate the effect of OVER and UNDER response other than through the direct measure of response time. There is no way to determine or indicate the effects of bias and prejudice on the

success of the dispatching strategy. In addition, the relationships between the outcome of service to the priority one customer and travel time is highly speculative. No one has proved that arrests will increase if response times decrease. Also there are no data available correlating the probability of a customer awaiting service being victimized with the length of time it takes the server to arrive. Furthermore, even if it was possible to determine how likely it was for, say, a lockout customer to be victimized while waiting for the police to come, there is no way to predict whether the person will be robbed, or beaten or murdered.

As a result, in order to evaluate the preemptive dispatching strategy, it is necessary to reduce the decision tree. Emphasis will be placed on the second and third sequences (Figures 3-2, 3) as there is not enough meaningful data available to justify evaluating the sequence. A spatial simulation will be run so that the dispatching strategy can be evaluated as if it were part of an operational CAD system. That is, urgent calls will be generated in an appropriate, hypothetical spatial distribution of busy and free servers. The spatial preemptive constraints will be applied. Then the expected utility of preempting eligible units will be compared to the expected utility of dispatching the closest free unit.

Even with the elimination of sequence one, there are a number of assumptions that will have to be made. (1) The probabilities of victimization and screening accuracy should each be varied in sensitivity analysis performed on the dispatching strategy, because the values used do

not represent historical statistics but are only "best guesses". (2) NO SHOW and NO RESPONSE will be eliminated. (See Appendix C).

F. Probabilities for Modified Tree

Prioritization is an aspect of preemptive dispatching that is of critical importance. The potential problems with screening cannot be understated. For a detailed look at the screening process see K. Stevenson and T. R. Willemain,[49] "Analyzing the Process of Screening Calls for Emergency Service", TR-08-74, IRP, Operations Research Center, MIT and the discussion in Chapter Nine. However, for our purposes at this time let me make the following assumptions.

I am assuming 20% of calls received are for emergencies (See Table 3-1a).[50] Historically if a call is described as an emergency 25% of the time it really is an emergent crime, while for a call that is described to be a nonemergency 40% of the time it is a crime. 10% of these crimes are emergent, while 90% are nonemergent crimes. With regard to screening accuracy, I am assuming that the dispatcher is correct 80% of the time.

Consequently Figure 3-4 shows that

P (preempt and correct) = .0656

P (preempt and incorrect) = .1836

P (don't and correct) = .7344

P (don't and incorrect) = .0164

Table 3-1a

RADIO CALLS AND CRIMES REPORTED

TYPE OF CALL	ALL RADIO CALLS	PERCENT OF TOTAL	RADIO CALLS WITH CRIMES REPORTED	PERCENT OF RADIO CALLS
1. Emergency (all blue)	724	16.5	179	24.7
2. Nonemergency but urgent (white/Code2)	274	6.3	67	24.4
3. Nonemergency (other white)	3,378	77.2	1,368	40.5
Total	4,376	100.0	1,614	37.0

Table 3-1b

CLEARANCE OF RADIO CALLS WITH CRIMES REPORTED

TYPE OF CALL	UNCLEARED CRIMES	ARRESTS MADE	OTHER CLEARANCE	TOTAL CLEARED	TOTAL RADIO CALL CRIMES
1. Emergency (all blue)	116	53	10	63	179
(Percent)	(65)	(30)	(5)	(35)	(100)
2. Nonemergency but urgent (white/Code 2)	38	23	6	29	67
(Percent)	(57)	(34)	(9)	(43)	(100)
3. Nonemergency (other white)	1,138	151	79	230	1,368
(Percent)	(83)	(11)	(6)	(17)	(100)
Total	1,292	227	95	322	1,614
Percent	(80)	(14)	(6)	(20)	(100)

Note: taken from Science and Technology, p. 93

This allows us to determine the probability of any probabilistic sequence of events of the type, first - we are told the call is an emergency, second - in fact it is not an emergency and, third - it is classified as an emergency. This would be an example of an over response where a nonurgent call is answered by a busy unit with probability = .1836. This corresponds to the probability at the end of the incorrect branch when the dispatcher has decided to preempt.

In turn, this data can be used to determine probabilities like $P[\text{correct}|\text{preempt}]$

	Preempt	Don't Preempt	
Proper	.0656	.7344	.8
Incorrect	.1836 (over)	.0164 (under)	.2
	.2492	.7058	

$$P[\text{PROPER}|\text{PREEMPT}] = \frac{P[\text{PROPER \& PREEMPT}]}{P[\text{PREEMPT}]} = \frac{.0656}{.2492} = .2632$$

$$P[\text{OVER}|\text{PREEMPT}] = \frac{.1836}{.2492} = .7368$$

$$P[\text{PROPER}|\text{DON'T PREEMPT}] = \frac{.7344}{.7508} = .9782$$

$$P[\text{UNDER}|\text{DON'T PREEMPT}] = \frac{.0164}{.7508} = .0218$$

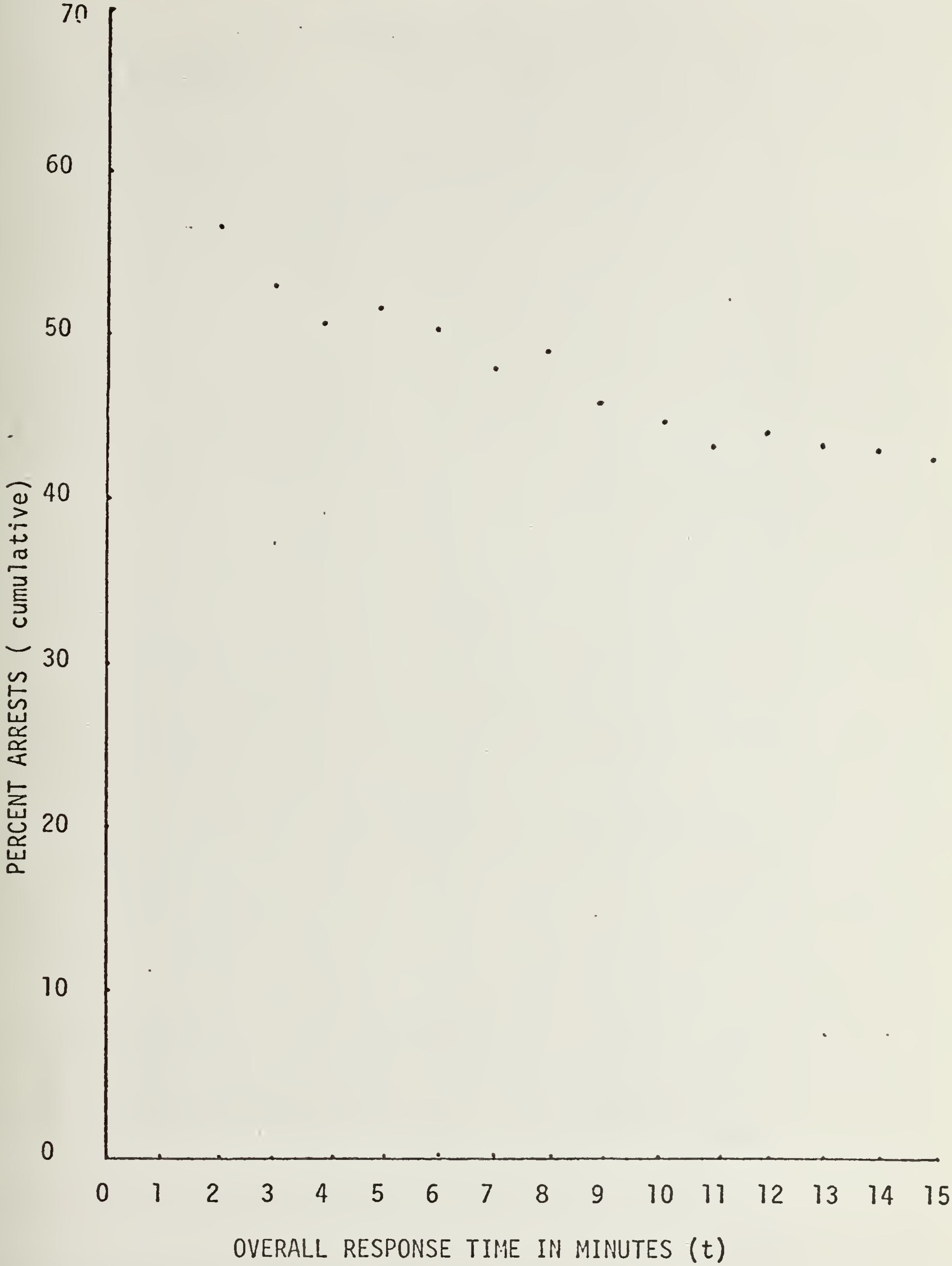
In the third sequence, there is a set of branches which describe the service that is received by the urgent customer; the police will

either ARREST the suspect, SCARE him AWAY or be TOO LATE. It is assumed the probabilities of these outcomes are a function of the amount of time it takes a patrol unit to arrive at the scene. The specific probability function that will be used has been derived from a curve of the percent of arrests in relation to overall response time" in the Science and Technology report for The President's Commission on Law Enforcement and the Administration of Justice.

The original curve is found in Figure 3-5. Because the range of time that was used for our model's description of the maximum response time to an urgent caller was 25 minutes (see Chapter Five, Attributes.), the curve's range was extended to that value. Furthermore, it was assumed that if a suspect was not arrested he was either SCARED AWAY or the POLICE were TOO LATE, and that the probability of the suspect being SCARED AWAY should decrease, while the probability of being TOO LATE should increase, with progressively longer response times. A table of the probabilities of ARREST, SCARED AWAY, and TOO LATE is found in Table 3-2.

The probability of victimization was assumed to be .05. There was no attempt to correlate victimization with arrival time.

Figure 3-5 Probability of Arrest as a Function of Response Time



source: Science and Technology, p.93.

Table 3-2

P[OUT1|TRAV1]

t	P(ARREST)	P(SCARE AWAY)	P(TOO LATE)
1	.62	.30	.08
2	.57	.33	.10
3	.53	.40	.07
4	.51	.36	.13
5	.50	.36	.14
6	.49	.35	.16
7	.48	.35	.17
8	.47	.34	.19
9	.46	.34	.20
10	.45	.33	.22
11	.44	.33	.23
12	.36	.32	.32
13	.34	.31	.35
14	.32	.29	.39
15	.30	.26	.44
16	.26	.24	.50
17	.23	.22	.55
18	.20	.20	.60
19	.17	.19	.64
20	.15	.17	.68
21	.12	.16	.72
22	.10	.15	.75
23	.05	.12	.83
24	.02	.11	.87
25	.00	.10	.90

IV. DISCUSSION OF PERFORMANCE MEASURES FOR THE POLICE

A. Introduction

Step 1 structuring the problem and step 3 quantifying preferences requires that (1) attributes for measuring performance are identified, and (2) they are scaled meaningfully. But there are many considerations that must be recognized before appropriate measures can be chosen and evaluated.

At this point the spatial model, which provides the foundation for the preemptive dispatching strategy, relies solely on the administrator's cost curves which define the permissable difference in travel distance between a busy nonurgent unit and the closest free car to the urgent caller. Effectively, the administration has provided a set of indifferences curves between urgent (D_b-D_f) and nonurgent (D_r) distances. As the difference between the closest busy unit and closest free unit increases, the allowable preemptable radius also expands. Nonetheless, although these curves are "intuitively nice," they can hardly be considered an adequate measure of the value of a preemptive dispatching strategy. Police responsibilities are more inclusive and require more comprehensive measures.

The difficulty that arises in determining appropriate measures for the police department is that it is a public service bureaucracy

that is accountable to the public and their subjective appraisal, and is "objectively" evaluated in comparison to other departments. The police find themselves in the position of trying to meet two different goals, which are not necessarily equivalent. Their efforts often lead to confusion and misunderstanding. Performance measures are needed that recognize this problem and honestly attempt to alter a stagnant situation.

B. Problems - Indicators

There are many indicators of the problems at hand. Many performance measures that are currently in use are inadequate. In general, many of the "objective" measures such as the number of arrests or clearance rates are not only inaccurate and misleading, but they reveal very little about the quality of service that is provided. Measures which reflect the competence of police personnel or consumer satisfaction are rarely employed.

Police role is also undefined and it frequently changes. The public image of the police is inconsistent and stems, in part, from American's desire for protection, but resistance to authority and interference. Unfortunately, the police have not demonstrated a better cognizance of their identity. There is little effort to break away from comfortable old polices and procedures, by the police or the public because "many an indicator confirms or reinforces existing conceptions rather than argues to alter them." [51]

It is obvious that any suggested improvement in police performance that is new, or clashes with old norms, will require a basic alteration

in both police and public attitudes before it is accepted. Although law enforcement is a community endeavor that should demand community participation extensive study will have to be undertaken to understand the institutional interaction that will take place with new policies.

While analyzing a preemptive dispatching strategy, it is clear that early emphasis must be placed on establishing what "consensus" is in the local community and on assessing the impact of implementing such a strategy. Then a system of checks and balances will be needed to insure that not only are the people protected against the police, but also against their own transient impressions. This will help to establish police role.

C. Measures - Considerations

The selection of performance measures is a difficult task. Once the objectives are defined the first matter is to determine what measures of effectiveness are appropriate and useful. A citizen survey is probably a reasonable means to ascertain the most important areas of citizen concern. It has immediate advantage that the public would recognize the interest the police are showing in their opinion and respond in kind.

The survey can provide a great deal of valuable information. An administrator could use the survey to identify fears, needs, as well as areas of satisfaction, and other subjective criteria that would help him delineate the basic nature of police service that is expected by the community. Correlation of the data by race or ethnic group could further clarify the community profile.

Once the problems are identified, performance measures should be generated that help induce the intended change and maintain accountability. They should indicate the results of the endeavor and allow analyses of the job performed. Subsequent police service would be more likely to be structured about citizens needs rather than what the police think the public wants.

An important decision, especially when considering a decision analysis approach to preemption is, "which is better - objective or subjective measures?" Utility theory is particularly well suited to evaluate subjective measures, but they are a topic of considerable controversy.

In many instances it is difficult to determine which measure is more appropriate. Objective and subjective measures each have advantages as well as disadvantages and it is recognized that often the measure that is preferred will be determined by an administrator's personal preference and the ease with which a measure can be conceptualized and manipulated. But, is it better to ask citizens about "fear," or should the percentage of households which have more than one lock on their doors be used as a surrogate measure?

A valid argument for subjective measures is that all measures do not have numerical substitutes. For instance, people have fears that are not rational, but are nonetheless real. A statistic of the probability of being mugged is not an appropriate or accurate substitute. Objective measures cannot be used to provide all measures of feelings and their priorities.

Nevertheless, whatever measures are chosen, it is important that these indicators are exact, unambiguous, and leave little doubt as to the direction of change. A survey that might be used to evaluate subjective measures must be especially well designed. The explanations of the intent of the measure can easily become imprecise because subjective measures cannot be explained with mathematical expressions. They describe "feelings." As a result, an unintended but significant bias could occur.

The Field Survey on Victimization and Attitudes found "despite the most intensive instruction we could afford to provide our interviewers and the high degree of specification and standardization we established for the interviewing procedure, we observed considerable variation from interviewer to interviewer in the average number of reports of victimization his completed interviews contained." [52]

An interesting issue that is perhaps premature is the validity of subjective measures as nationally used performance measures. Certainly emotions such as "fear," "anxiety" and "satisfaction" have a connotation that is understood nationally, that we might be able to measure. However, I feel they will be criticized as being ambivalent and abstract, just as current objective nationally used performance measures are now.

Specifically, nationally used subjective performance measures seem inappropriate because the circumstances which create the setting in which the problem is evaluated are interpreted differently across the nation. People's subjective feelings have a peculiarly local nature that would be, at the very least, extremely difficult to correlate on

a national or even regional level - although this would be a better procedure, if it could be accomplished. As a result, nationally used subjective performance measures would seem to coerce the police into a national competition between police forces, to achieve the national norms, which would create services that were in other than the community's best interest.

A more pertinent question, that might logically precede what performance measures are to be used is, "Who determines what measures are appropriate?" Can the police make up their own performance measures? Should they? If they don't, who is qualified to determine these measures?

I think the police know their job better than any other single group of individuals. Although they can be accused of ignoring certain problems, and public emphasis might differ as far as which problem is more important and which procedures are more acceptable, they have the necessary experience and insight to know what problems exist and what can be done about them. The question that arises is, "Who will benefit if the police chose their own performance measures?" Or can the police honestly gauge their own performance?

There are a number of approaches one can take. (1) Let the police make up their performance measures. (2) Allow the public to make up the police performance measures. (3) Let the public create and evaluate the police by one set of performance measures, while the police use another set, then weight the two relative to one another and combine them. (4) Try to achieve an interactive a priori consensus.

Each approach has advantages as well as disadvantages. The fourth proposal involves an extensive education program between the two groups. This was achieved rather successfully on a small scale with the New York Civilian Complaint Board. Also, the Rand Institute, and Sellin and Wolfgang have done studies using expert panels to direct complex efforts.[53] The necessary interaction creates a beneficial awareness and respect between the two groups. However, the process of selecting the proper mix of qualified people to be on the board is difficult and consensus may be impossible to achieve.

The third would be easier, initially, because theoretically no agreement is necessary, and a sensitive weighting may achieve the same results. But there would be considerably less interaction between the police and public.

One major objection to the police making their own performance measures is the potential that exists for these measures to become self serving. Professionalism can promote competiton between the "professionals" and the "civilians." The police seem to become sensitized toward reactions against "their" goals. If they didn't make the measures they might feel less autocratic and be less easily offended.

But, should the public determine police performance measures? In general, the public does not comprehend the daily pressure which a policeman faces. They do not relate to the helplessness a policeman may feel when trying to stop a known pusher within the legalities he is constrained to honor. Public isolation may be a benefit that allows a

broader perspective of a situation or it may represent a position of ignorance that adds little or no insight.

Surely, there are persons within each group who are capable of detachment and perception. But, how are they identified and best employed? Is there a method that can insure that they will always be identified? If not, which method is more consistent?

Urgent vs. Nonurgent. A similar set of issues can be raised with regard to urgent and nonurgent customers. Not only is there the question of whether or not the police know what is best for the victim, but can the urgent customer understand the nonurgent customer's problem? and vice versa?

Does an urgent customer, like a person being robbed, care that a robbery victim of two days ago is preempted so that he can receive quicker attention when there seems to be a limitless supply of services. I do not think so. Self interest seems to dominate idealism. In fact, it would be hard to convince many policemen that any victims care about their fellow man, becuase they have had too many encounters with selfish citizens.

In this situation, the police may have a better perspective of a client's needs, in general, than the individual clients themselves. I think it is clear how each group can compliment the other.

D. Conclusion

Selecting performance measures for a preemptive dispatching strategy for the police is a complex undertaking. The measures that are selected

must not only be able to describe the changes that occur as a result of the new policy, but they must be capable of insuring that the structure is implemented as it is defined as well. Preemption is a strategy that will be very sensitive to the attitudes of the police and the public. It will not succeed unless police role is well defined in both the police and public mind.

Utility Theory is particularly well suited for constructing this demanding set of measures becuase it can incorporate objective and subjective measures as well as the character of the people who are involved. The degree of sophistication in this evaluative, or transitional stage need not be extensive while the methodology is identified, tested and refined. But if the measures that are selected, pertain only to preemption and its easily measureable direct consequences, rather than the total system perspective of preemption and its impact, then the analysis will be too narrow and the strategy could easily fail.

V. ATTRIBUTES

A. Introduction

To find attributes that can be used as performance measures it is helpful to begin by delineating the groups of people who are most concerned with the impact of the strategy. The performance measures chosen should serve to satisfy their expectations or fears.[54]

Basically, there are two groups interested in preemption. The police, who is the server, and the public - the customer. Within each group a further distinction among the members can be made.

The police can be categorized as (1) "patrolmen", (2) "operations personnel", and (3) "administrators". The "patrolmen" are the officers who work directly with the public. They man the patrol cars. "Operations personnel" are the communications division of the police force and fill the complaint operator jobs or act as dispatchers. The "administrators" refer to people like the police chief and the police commissioner who are charged with the overall operation of the police force, including its political aspects. The customer can also be categorized. The differentiation will be between "urgent" and "non-urgent" customers. These distinctions represent a new emphasis, because until now performance measures, in general, have ignored or played down the customer and his opinions.

The important distinction that is being emphasized by recognizing two groups, and the different categories of people wihin each, is their individuality. Whereas the patrolman is interested in the content of his

job and his own workload, the dispatcher is cognizant of the needs of all customers awaiting service and of the overall requirements for effective system operation. Likewise, the public at large sees the police enforcement problem differently than the victim, while there is a further distinction between the outlook of urgent and nonurgent victims. On top of this, it is the administator's job to balance the proactive cries of the public at large, against the reactive cries of victims and the demands of the Police Benevolent Associations. This is in no way meant to imply that each group will always have a different attitude on a given problem, but only that the model should be able to account for that circumstance.

In either case, distinguishing between groups, with possibly different opinions, provides a flexibility within the model that allows us to test various combinations of different degrees of these attitudes to see which best represents reality.

B. General Assumptions

The number of proposed performance measures have been kept to a minimum. They have been chosen so that the implications of a consequence are clear while the mathematics remain as simple as possible.

Both subjective and objective measures have been incorporated. When subjective indicators are used the specific attributes have purposefully been selected so that there is enough differentiation between each one that the confusion of making five distinctions is minimized,

but the measures remain meaningful.

I have assumed that citizens are not entirely objective in their evaluation of the service they receive. In general, they weigh objective measures against relatively more important subjective measures to determine their opinion of the service they received. On the other hand, I have assumed that the police are more objective in their evaluation of the job they perform. I think this is a valid assumption that recognizes the distinction between a customer's emotion and a policeman's experience or professionalism. This is not meant to imply that one is objective and the other subjective. Instead it is being discussed to illustrate a difference in attitudes that could exist and should be recognized.

For instance, a response time in minutes that can be compared objectively to other police departments' performance is important to the client, but it is weighed against the outcome of the service received, such as, whether or not the criminal was arrested. The customer is concerned with the success of service received and not how long service took but the anxiety, satisfaction, or inconvenience it causes him.

I feel it is reasonable to assume that the police would be more content with objective measures. They perform a reactive task and are expected to maintain system efficiency. If we are focusing on their feelings towards their job, they are most concerned with the aspects of service that are within their means to improve. Their expectations

tend to be more consistent and rational, consequently more absolute measures such as travel time are more acceptable, although the police must assess their own utility function like the customers.

C. Specific Attributes

In order to facilitate the discussion that is to follow I will first list the eight categories of attributes that have been chosen to measure preemptive service. Four categories will be used to measure service from the customer's perspective. The other four categories will be used to measure the police evaluation of the service they provide. Each category of attributes describes a particular aspect of police service that it is felt needs measurement. The attributes represent different levels within a category that may result from various sets of circumstances. Each category will be given a short acronym that will describe the function of that component of the measures.

The name of the group of interest, the category name and the associated levels can be found below.

Customer

Urgent customer		Nonurgent customer	
OUT 1	NERV 1	OUT 2	NERV 2
CHARGE	0	Victimized	0
CONVICT	.		.
ARREST	.		.
SCARE AWAY	.	Not victimized	.
TOO LATE	25 mins		90 mins

Police

ACCU	TRAV 1	JOB 2	TRAV 2
PROPER	0	Cat in Tree	0
OVER	.	Drunk	.
ORDER	.	Burglary	.
NO RESPONSE	25 mins	Suspicious Person	.
		Lockout	.
		Family Quarrel	90 mins
		Vehicular Accident	

C.1 Customer Attributes

Two performance measures have been chosen for the urgent customer. The first, whose name will be OUT 1, measures the degree of success the police had after servicing the priority one customer. There are six possible levels of this component. [Although the terms used are meant to be self explanatory, all terms are defined in the glossary]. They are CONVICT, CHARGE, ARREST, SCARE AWAY, TOO LATE and NO SHOW. CONVICT is considered the best level of service the system can provide, while NO SHOW is the worst level.

The name of the second measure will be TRAV 1 and it measures the waiting time an urgent customer experiences between when the call for service was placed and the police arrive on the scene. The range of this measure is 0 to 25 minutes.

As has been mentioned, it is felt that the customer is concerned with the results of the service he receives. Consequently, OUT 1 was proposed. NERV 1 compliments OUT 1. For instance, if a criminal is arrested and then convicted, the customer probably doesn't care whether service took five minutes or twenty minutes to arrive, although if the arrest and conviction took six months there probably would be

some distinction. On the other hand, if the police SCARE AWAY the criminal, or were TOO LATE, the customer will be much more understanding if his wait was two minutes instead of sixty minutes. [For a further discussion on NO SHOW see Appendix B]

These measures account for valuable tradeoffs. It is recognized that a potentially useful refinement for later models should probably differentiate between varying degrees of fear created by the different crimes, because "all crimes are not equally undesirable". [55] But, in general, these measures provide a simple but relatively complete description of the service received by an urgent customer, and his feelings.

The nonurgent customer also has two performance measures. These components will be called OUT 2 and NERV 2. For the nonurgent customer the levels associated with OUT 2 will be VICTIMIZED and NOT VICTIMIZED. The term "victimized" is intended to have a broad meaning. It is being defined to describe any unpleasant consequence that is a result of preemption. It will pertain to a lockout victim who is mugged after their service has been interrupted as well as a situation where there is a traffic jam because the attending officer was dispatched from an automobile accident to another job. Eventually the model should correlate the type of victimization to the type of incident that was interrupted. But at this stage of analysis it is felt that a single measure will convey the necessary information.

It should be noted that in Newark, New Jersey preemption was not considered viable because of the high probability that certain preempted

customers might be subsequently victimized while waiting. This might be a genuine problem in some parts of Newark, and parts of other large American cities. Of course, in many situations it may be unreasonable to believe the customer could be victimized. However, the fear of subsequent victimization among the public may outweigh the other benefits of preemption - and should victimization occur OUT 2 would acount for these circumstances.

The range of NERV 2 is 0 to 90 minutes. It is felt that most persons will group their feelings towards their wait into groups that might be called short, medium or long. But significant variations are more likely to be a function of the number of times a customer has had service interrupted, or how long it took for the first policeman to arrive.

C.2 Police Attributes

The four components that have been proposed for the police pertain primarily to the operations personnel, because although there is a distinction between operations personnel and the patrolmen, it would not add any additional insight, at this stage, in the evaluation of preemption. Instead, concentrating on systems personnel allows us to emphasize a concern that exists for system performance.

The first measure will be called ACCU. It measures the accuracy of the dispatching process. The levels that will be used are PROPER, OVER, ORDER, and NO RESPONSE. [See Appendix B for discussion of NO RESPONSE] The PROPER is considered to be the best level the system

can attain, while NO RESPONSE is the worst level.

Preemption requires that the complaint operater assign a priority to all incoming calls. Naturally, the priority classification in a preemptive dispatching strategy directly affects the speed of service. The effectiveness of prioritization has an important effect on the strategy's success, as does the dispatchers decision whether to preempt should the situation be "preemptable". ACCU is intended to provide a measure of the success of this strategy.

With regard to the urgent customer, system personnel are concerned with the travel time to the scene. The second component of the police measure is called TRAV 1. Its range is also 0 to 25 minutes like NERV 1.

In general, it is felt the police will be content with ACCU and TRAV 1 as measures of their performance to the urgent customer because given that they know if the call was handled properly their only concern is that the assigned patrol unit got there as quickly as possible. If they do their best, there is not much else they can do.

TRAV 2 is the name given the measure of travel time to the nonurgent preempted unit. It is scaled between 0 and 90 minutes, like NERV 2. This, too, is a logical measure because systems personnel would like to provide service as quickly as possible to the nonurgent preempted customer.

The final measure considers the nature of the (job) incident whose service is interrupted. It provides a means to evaluate the

disruption preemption causes to the system. It is named JOB 2. The possible levels that will be defined represent only a few of the many incidents that might be preempted. They are CAT IN A TREE, DRUNK, BURGLARY (in past), LOCKOUT, SUSPICIOUS PERSON, FAMILY QUARREL, and VEHICULAR ACCIDENT. CAT IN A TREE is considered the best choice and VEHICULAR ACCIDENT is the worst level.

Intuitively, this is also a logical measure. If the dispatcher had a choice, it would be better to preempt a policeman getting a CAT IN A TREE than one settling a FAMILY QUARREL. Also, there should be less anxiety from the customer's standpoint and less chance of unfortunate repercussions. The Task Force Report on Science and Technology supports this premise: "the tradeoffs among different types of crime are an important consideration in allocating enforcement resources". [56]

The previous eight performance measures have been proposed as indices for a preemptive dispatching strategy. They are chosen to measure the value of service for the police and customer. The final, overall system objective cannot be known until all utilities are evaluated, weighted and are appropriately combined.

These measures are proposed as an initial list of measures that can be used to construct a multiattribute utility function, which will include objective as well as subjective measures for evaluating a decision process in the police public service system.

VI. GROUP MULTIATTRIBUTE UTILITY FUNCTIONS

A. Introduction

The police response problem is a multiobjective endeavor. Each of the performance measures that has been chosen reflects an aspect of service that is of concern to a particular group of people that will be affected by a preemptive dispatching strategy. These measures are not divorced from one another. They are interrelated and tradeoffs are made between attaining different levels of one attribute for another. Utility theory allows us to construct a single function that will evaluate any consequence of various levels of all the attributes that have been chosen. It is known as a Multiattribute Utility Function (MUF). MUFs of different distinct groups such as the police and the customer can be combined into even larger functions known as GROUP Multiattribute Utility Functions (GMUF).

The object of this section is to form a Group Multiattribute Utility Function composed of the Multiattribute Utility Functions for the police and the customer. This will enable us to meaningfully evaluate the consequences of any alternative or action. The MUFs and GMUF will be constructed to describe the inherent tradeoffs that take place as decision makers evaluate multiple objective problems.

The numerical analysis that will occur will be based on the author's assessments of (1) the single attribute utility function, as well as, (2) the relative weightings that are required. This has been done because the structure and approach of decision theory and the technique

of constructing and evaluating GMUFs in a police arena is the concept that is being emphasized, not necessarily the construction of a rigorous, "real world" model. Consequently the points that will be made focus on establishing which attributes are most important and then seeing how they can be varied by themselves or perhaps in groups to mirror the decision maker's true feelings. Because the decision maker in this paper is the author, it is felt that it is more appropriate to keep the discussion in the theory realm rather than dwell on the utility function's interpretations or speculate on their impact in the real world.

The discussion in this chapter assumes a certain knowledge of Decision Theory and Utility Theory on the part of the reader. A more detailed discussion of the theory and mathematics involved can be found in Appendix D. It is felt that an understanding of the procedures that are followed and the reasoning that is used in constructing the MUFs should be presented in a single chapter so that the reader can most easily follow the construction process. The mechanics are tedious; they only define the form of the function. The ultimate test is whether the model agrees with the decision maker's feelings.

B. Specific Procedures

The questioning that takes place in assessing a utility function for the police or the public is meant to not only identify the decision maker's utility over a range of attributes within a category, but also to determine the relative weightings (scaling factors - k_i) of the components that will be needed to construct the MUF. Thus, the trade-

offs between attributes is recognized and can be described within the function.

However in practice, the assessment is performed by more than one person. Because different persons' opinions are not the same, just as different groups have their own opinions, this imples that the MUF for the police or public is in fact a GMUF. This observation is significant because there are special mathematical techniques that are used to construct GMUFs.

The concept of forming GMUFs is quite simple. It is analogus to relatively weighting different components. The only difference is that, in this case, people receive relative weights. A function can be constructed to reflect an individual's wealth, political influence or special expertise within a given field. However, for the purposes of evaluating a preemptive dispatching strategy, if a survey were taken, it would probably be more appropriate to assume that each person's opinion is as valuable and valid as another's, and weight each equally. (As has been mentioned, in this paper, the author will make all evaluations.)

C. Single Attribute Utility Functions

The first step in beginning to construct a MUF is to assign a "value" to each of the levels that were defined for the eight attributes chosen as performance measures in the previous section. In many instances money is an appropriate measure of the value of a particular

consequence. This is very convenient because when trying to evaluate which decision is best, it is simply the one that maximizes your expected gain. Unfortunately, all attributes do not have a meaningful monetary surrogate. For instance, what is the "cost" of fear.

Utility Theory developed from a need to be able to deal with this type of problem. It is based on man's ability to scale his preferences between the "best" and "worst" imaginable situations. The "utiles" of an attribute are an index or measure. Once an attribute has been converted to utiles it is appropiate to associate with each lottery its expected utility, just as was the case with dollars before.

Thus the values that are sought for the levels of the attributes that have been chosen are their "utilities". However, if a survey were to be compiled there is a problem that must be considered. The people who will be questioned to assess their utilities may not be able to understand the required lottery and tradeoff questions.

Fortunately, a very "neat" method for introducing decision theory to people who are to be surveyed has been developed and successfully tested by Hauser and Urban.[57] It provides a particularly clear, concise format for assessing a person's utility, and it would be invaluable in this context.

However, to avoid the confusion of defining a representative sample and interpreting the results the author has assessed the utilities of the levels that have been described in the previous chapter. A

utility function over a particular performance measure component will be devoted by $U_{\substack{\text{component}\\\text{name}}}$ (attribute or consequence). For example, the utility of the attribute CONVICT of the component OUT 1 will be $U_{\text{out 1}}$ (CONVICT). (The definition of all components and attributed are found in the glossary at the end of the paper). The utility functions are drawn in Figures 6-1 and 6-2.

It is worth mentioning, that the reader will discover that $U_{\text{nerv 1}}$ (NERV 1) and $U_{\text{nerv 2}}$ (NERV 2) are nearly discontinuous at certain points. (Referring to Figure 6-1.) This was done purposefully to describe how a customer will gradually become dissatisfied until he has waited about 10 minutes. Then there is a distinct change in his mood, which is reflected in a sharp drop in his utility, because perhaps now he is impatient. He remains impatient until about one hour has passed. At this point he becomes angry or disgusted, which is accompanied by another sharp drop in his utility. It is felt that this is probably a more accurate description than a continuously smoothly decreasing utility function.

D. Multiattribute Utility Functions

The next step is to construct the MUFs (in reality the GMUFs) for the police and the customer. This will permit the utility of any four attribute consequences, for either group, to be expressed as a single numeraire that has been constructed to accurately represent the true multiple objective nature of the problem.

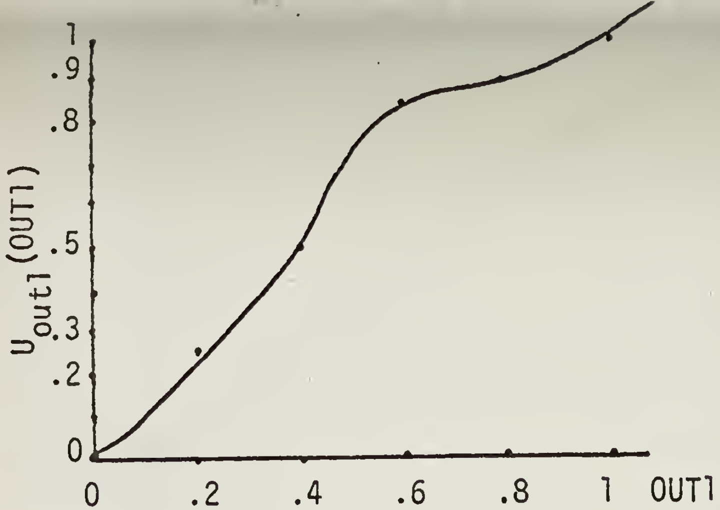


Figure 6-1a

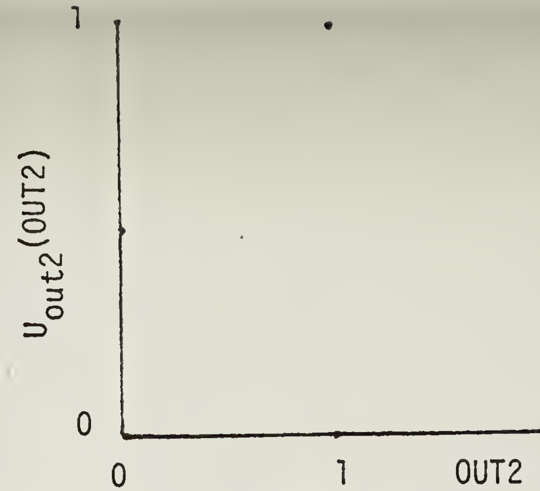


Figure 6-1c

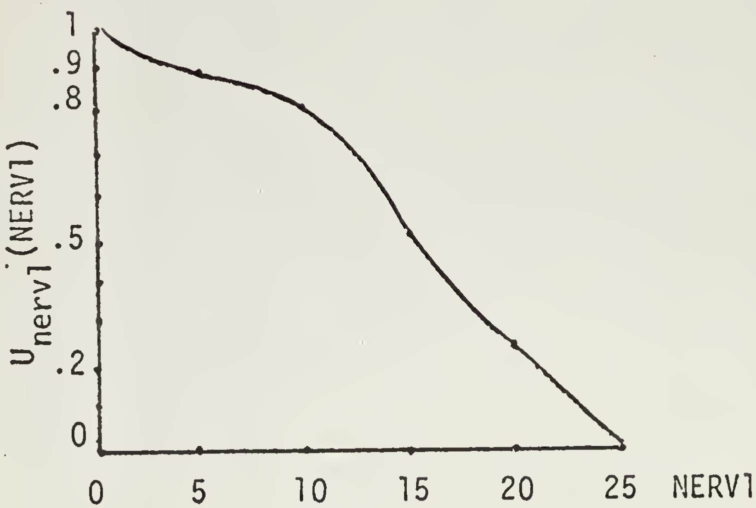


Figure 6-1b

Figure 6-1d

Figure 6-1 Customer Single Attribute Utility Functions

Figure 6-2a

Figure 6-2c

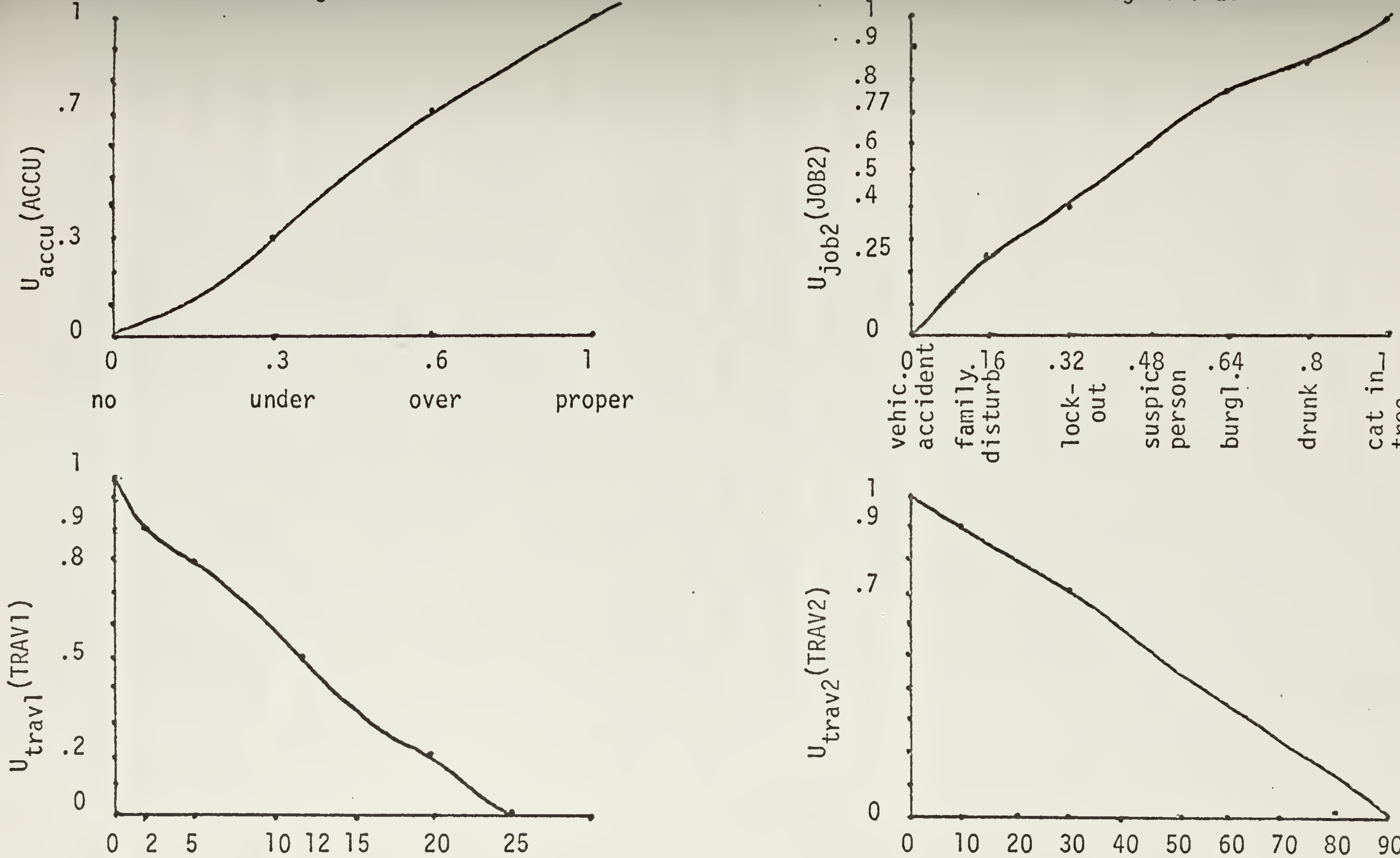


Figure 6-2b

Figure 6-2d

Figure 6-2 Police Single Attribute Utility Functions

D.1 Notation

For notational convenience we will define a "consequence" to be a multiattribute description of the outcome of an action. The outcome of action i will be designated by $\underline{C}i$. The utility of a vector consequence will be described by U ($\underline{C}i$).

The utility of a "strategy" will be described by U (PREEMPTION) where PREEMPTION defines a specification with well defined consequences.

The expected utility of a strategy will be defined as E U(PREEMPTION).

D.2 Unique Functional Forms

Should the performance measures that have been selected meet certain very stringent conditions, the utilities of each performance measure (component) could be added together to form a MUF assessment of any consequence. However, these conditions are often unrealistic, and the assessment procedure is very difficult and tedious to perform. There are more general additive and multiplicative forms that have been identified that we will tru to use that require that less stringent initial conditions are met and are also simple to compute.

Much work has been done in this area by Keeney.[58] He has shown that if utility independence and preferential independence can be assumed, then the form of the MUF is either additive or multiplicative. These assumptions enable the decision maker to determine the relative scaling factors (k_i), that describe the relative importance of the various attributes, through asking only a brief series of questions that locate an indifference curve and determine its shape. Because of the functional

form of the MUF and the fact that four attributes are being nested in the MUF, the problem is further simplified because one degree of freedom is gained and only three relative scaling factors - must be evaluated. The fourth scaling constant can be set at an arbitrary level. The absolute weights are then evaluated with one additional question.

D.3 Use of Interactive Computer Program

The assessment process for constructing a MUF is normally a slow, tedious problem. Extensive calculations are required. However, in this paper I have used an interactive computer program for assessing andusing multiattribute utility functions that was developed by Alan Sicherman. The program is described in a paper by the same name, which is Technical Report No. 111 Operations Research Center, M.I.T., June 1975.

"The program package provides routines for (1) specifying the decision maker's preference over multiple criteria, (2) treating uncertainty in the consequences resulting from a decision, (3) ranking alternative courses of action in order of preference, (4) studying the effects changes in preferences or uncertainty estimates may have upon the ranking of alternatives."[59] It is an invaluable tool that allows the decision maker the luxury of concentrating on the tradeoffs and alternatives that are the focus of the problem, without worrying about the many tedious calculations that are normally required. It is hoped the reader will benefit from this approach.

E. Evaluation

I have assumed that utility independence and preferential independence exist, so that Keeney's multiplicative forms are applicable. [For a further explanation see Appendix D.]

PRECUSTO ≡ Is the name given to a vector consequence that describes the service a customer receives, i.e., (OUT 1, NERV 1, OUT 2, NERV 2)

PREPOLO ≡ Is the name given to a vector consequence that the police provide, i.e., (ACCU, TRAV 1, JOB 2, TRAV 2).

GRANDMUF ≡ Will be the name given to a vector consequence consisting of all eight attributes which measures the overall system response to police service.

The MUFs will be described as follows:

$U_{PRECUSTO}(\underline{C}i)$ ≡ The MUF that describes the utility of the service a customer receives. It is measured over the vector of components described by PRECUSTO.

$U_{PREPOLO}(\underline{C}i)$ ≡ The MUF that describes the utility of service provided by the police. It is measured over the vector of components described by PREPOLO.

$U_{GRANDMUF}(\underline{C}i)$ ≡ The MUF that describes the utility of police service for the overall system. It is measured over the vector of components described by GRANDMUF.

E.1 PRECUSTO

Once the individual utility functions have been assessed, the next step in forming the customer's MUF ($U_{PRECUSTO}(\underline{C}i)$) is to determine the relative scaling factors of the four components, the k_i's are:

$$k_{out\ 1},\ k_{nerv\ 1},\ k_{out\ 2},\ k_{nerv\ 2}.$$

Their values will demonstrate, from the decision maker's perspective, the relative importance of the attributes to one another. These ratios are assessed by the program by comparing two pairs of two indifference

consequences of two attributes each. For instance, when trying to compute the relative ratio $k_{out\,1}/k_{nerv\,1}$, we would provide the following pairs of two attributes (OUT 1, NERV 1) consequences that were indifferent to one another, e.g. U(1,0) ~ U(.6,1) and U(.6,0) ~ U(.2,1) The three relative k_i's and the points that were evaluated are found in Table 6-1. Because there was one degree of freedom the k_{out1} was arbitrarily set at .8 such that

$$k_{nerv1} = .6$$

$$k_{out2} = .6296$$

$$k_{nerv2} = .6832$$

Then one additional indifference pair was selected to verify the values of the scaling factors. This indifference evaluation was between (OUT 1, OUT 2). The points used were selected so that U(.6,80) ~ U(.2,8). The program computed that all k_i's had to be multiplied by 1.091 to be consistent with the last information. Thus

$$k_{out1} = .8728$$

$$k_{nerv1} = .6546$$

$$k_{out2} = .6868$$

$$k_{nerv2} = .7453$$

and $K = -.996$, where K is a scaling factor that is a function of the k_i's. K is often called "Big K" to distingush it from the other k_i's.

From Keeney's work (see Appendix D), because the relative scaling

Table 6-1a

INDIFFERENCE POINTS USED TO EVALUATE $U_{PRECUSTO}(\underline{C}_i)$

PRECUSTO (OUT1, NERV1, OUT2, NERV2)

	FIRST PAIR	SECOND PAIR
(OUT1, OUT2)	(1, 0) ∿ (.6, 1)	(.6, 0) ∿ (.2, 1)
(OUT1, NERV1)	(.4, 24) ∿ (.2, 20)	(.6, 20) ∿ (.2, 2.5)
(OUT1, NERV2)	(.6, 80) ∿ (.4, 20)	(.4, 20) ∿ (.2, 8)

Table 6-1b

INDIFFERENCE POINTS USED TO EVALUATE $U_{PREPOLO}(\underline{C}_i)$

PREPOLO (ACCU, TRAV1, JOB2, TRAV2)

	FIRST PAIR	SECOND PAIR
(TRAV1, ACCU)	(2, .3) ∿ (7, .6)	(10, .3) ∿ (17, .6)
(TRAV2, JOB2)	(10, .16) ∿ (80, 1)	(18, .32) ∿ (40, .64)
(TRAV2, TRAV1)	(30, 10) ∿ (50, 5)	(20, 10) ∿ (40, 5)

factors (k_i's) do not sum to one, the function is multiplicative. There are dependencies between the attributes. Furthermore because K is close to -1 the function is compensating. That is, one attribute at its best will make up, or substitute, for the levels of the other attributes. We can also see that $k_{out1} > k_{nerv2} > k_{out2} > k_{nerv1}$. OUT 1 is the most important component. Now that the MUF is formed it is valuable to verify the accuracy of the function. There are two ways in which this can be accomplished. (1) plot indifference curves between various pairs of attributes and (2) evaluate a number of consequences and see if the rank ordering of the utilities of the function agree with one's intuition.

Indifference curves between U (OUT 1, NERV 1), U (OUT 1, NERV 2), and U (OUT 1, OUT 2) have been calculated and are shown in Figure 6-3. They increase the decision maker's awareness of the tradeoffs he has made in the construction of the MUF.

A total of 29 alternatives were created and stored. After they had been intuitively ranked they were evaluated using the MUF, $U_{PRECUSTO}(\underline{C}i)$ and the two rankings were compared. The function's ordering matched my own intuitive ranking very well. As a matter of fact, it uncovered some inconsistancies in my judgemental evaluation. The evaluation of a number of alternatives definitely helps the decision maker gain a better feel for the interaction that occurs between the four attributes (See Table 6-2.)

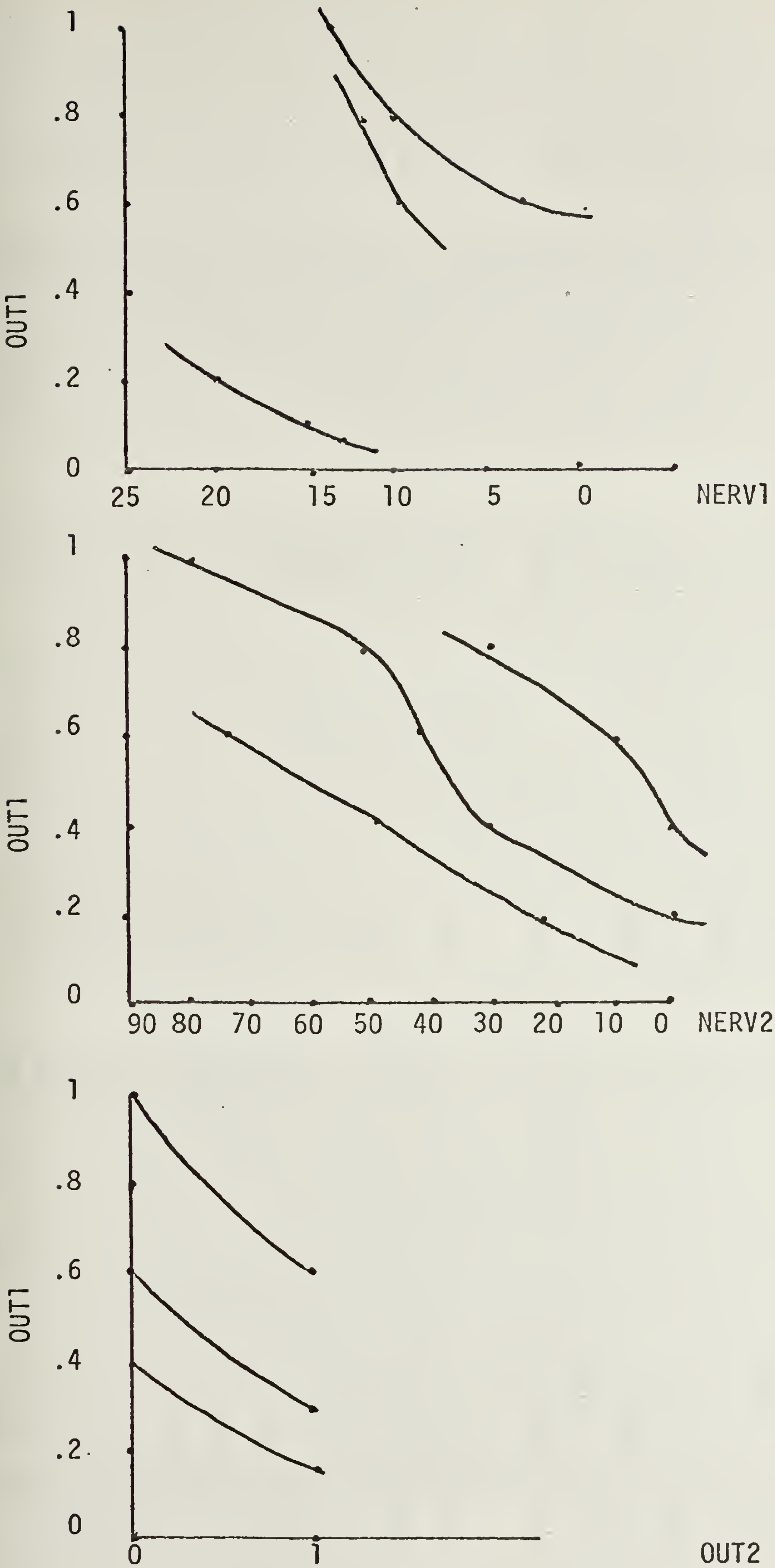


Figure 6-3 Indifference Curves-Customer

EVALUATION OF ALTERNATIVES - CUSTOMER

	PRECUSTO ATTRIBUTES				ORIGINAL K = -.966		PRECUSTO X1/2 K = -.703		ADDITIVE K = ADD.	
	OUT1	NERV1	OUT2 #	NERV2	U*	ORDER	U*	ORDER	U*	ORDER
Ca1	convict	10	V	29	.995	2	.934	3	.894	3
Ca2	charge	8	V	5	.995	2	.951	1	.923	1
Ca3	convict	12	V	5	.996	1	.940	2	.899	2
Ca4	charge	10	V	20	.991	4	.927	4	.886	4
Ca5	charge	5	V	20	.989	5	.912	5	.864	5
Ca6	arrest	10	V	20	.987	6	.902	6	.850	6
Ca7	convict	10	V	2	.987	7	.826	8	.719	8
Ca8	convict	5	v	20	.980	8	.797	9	.684	9
Ca9	scare away	5	V	20	.971	10	.843	7	.769	7
Ca10	convict	20	V	70	.973	9	.742	10	.615	10
Cb1	charge	5	v	12	.965	1	.770	3	.656	5
Cb2	too late	5	V	12	.959	3	.791	1	.696	1
Cb3	charge	10	v	20	.958	3	.750	7	.632	7
Cb4	arrest	5	v	25	.956	4	.754	6	.639	6
Cb5	too late	10	V	20	.952	5	.772	2	.673	2
Cb6	scare away	15	V	10	.948	7	.765	4	.666	3
Cb7	scare away	15	V	20	.947	8	.764	5	.664	4
Cb8	arrest	10	v	20	.949	6	.736	8	.618	8
Cb9	too late	15	V	15	.926	9	.704	9	.591	9
Cb10	scare away	5	v	20	.901	10	.576	10	.537	10

\# $\overline{V}$ - Not victimized; v - victimized.

* $U_{PRECUSTO}(\underline{C}ai(bi))$

E. 2 PREPOLO

The MUF, $U_{PREPOLO}(\underline{C}i)$ was evaluated in the same manner as $U_{PRECUSTO}(\underline{C}i)$. The indifference pairs that were used to determine the scaling factors can be found in Table 6-1b . With a single indifference pair between TRAV 2 and TRAV 1, U(30,10) ~ U(50,5), the scaling factors were determined to be

$$k_{accu} = .414$$
$$k_{trav\ 1} = .561$$
$$k_{job\ 2} = .519$$
$$k_{trav\ 2} = .561$$
$$K = -.926$$

$U_{PREPOLO}(\underline{C}i)$ is also multiplicative and compensating, although less so than $U_{PRECUSTO}(\underline{C}i)$. $k_{trav\ 1} = k_{trav\ 2} > k_{job\ 2} > k_{accu}$.

Indifference curves for U (TRAV1, ACCU), U (TRAV 2, JOB 2) and U (TRAV 2, TRAV 1) have been computed and are found in Figure 6-4.

A number of alternatives were evaluated to gain an insight into the tradeoffs that were taking place (see Table 6-3).

E. 3 GRANDMUF

E. 3a Formation of $U_{GRANDMUF}(\underline{C}i)$

$U_{GRANDMUF}(\underline{C}i)$ is the notation that will be used to describe the GMUF comprised of $U_{PRECUSTO}(\underline{C}i)$. It is formed in the same way $U_{PRECUSTO}(\underline{C}i)$ or $U_{PREPOLO}(\underline{C}i)$ were formed, except that now the

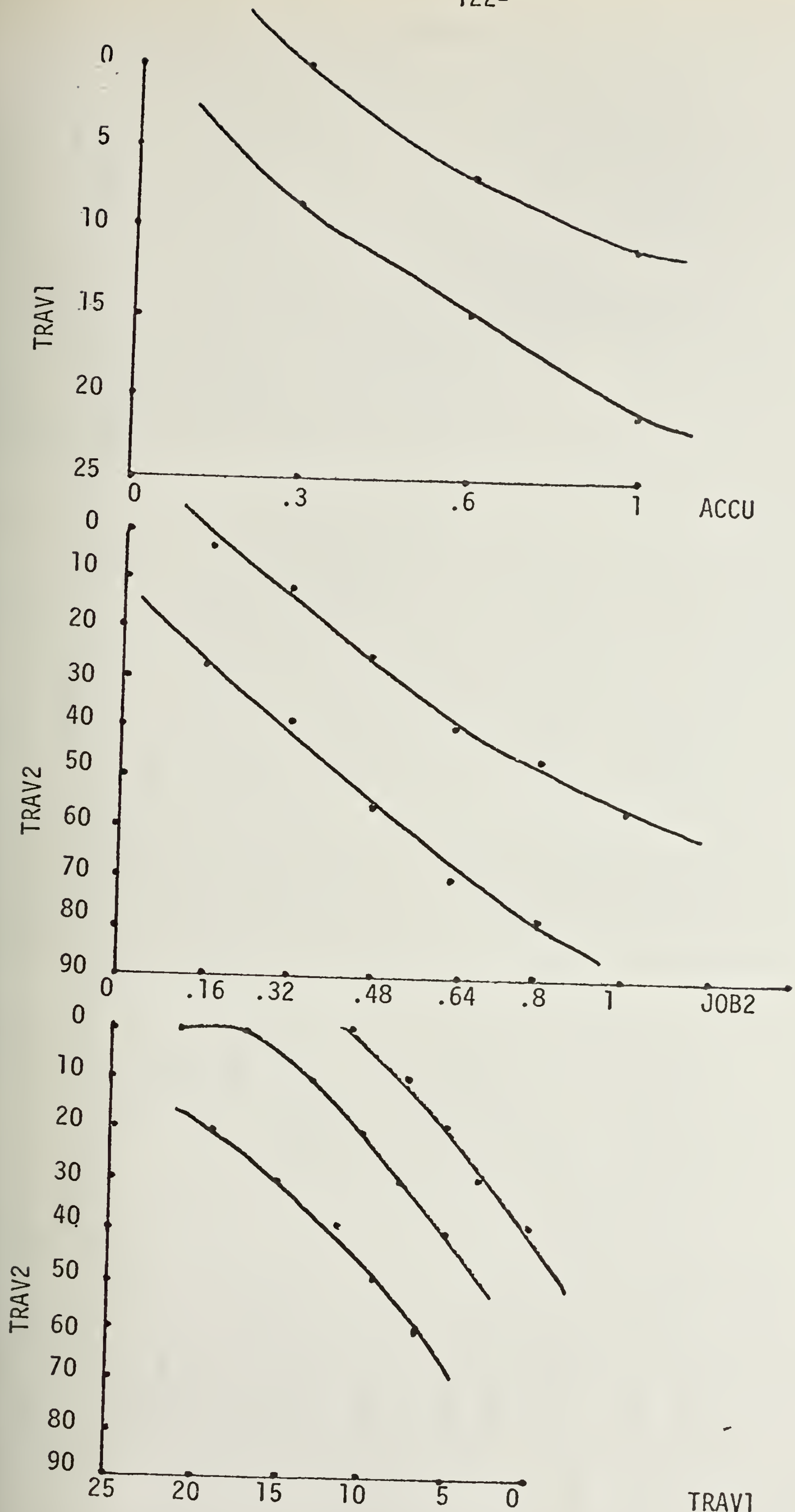


Figure 6-4 Indifference curves-Police

Table 6-3

EVALUATION OF ALTERNATIVES - POLICE

	PREPOLO				ORIGINAL		= ADD	
	ACCU	TRAV1	JOB2	TRAV2	$U_{PREPOLO}(\underline{C}(ai,bi))$	ORDER	$U_{PREPOLO}(\underline{C}(ai,bi))$	ORDER
$\underline{C}$ a1	proper	2	cat in tree	10	.982	1	.945	1
$\underline{C}$ a2	over	2	cat in tree	10	.964	3	.885	3
$\underline{C}$ a3	over	5	cat in tree	10	.952	4	.858	4
$\underline{C}$ a4	proper	2	suspicious person	10	.945	5	.844	5
$\underline{C}$ a5	proper	6	burglary	12	.942	6	.842	6
$\underline{C}$ a6	under	2	cat in tree	10	.939	7	.806	7
$\underline{C}$ a7	over	2	burglary	20	.925	8	.800	8
$\underline{C}$ a8	under	5	cat in tree	10	.925	8	.778	10
$\underline{C}$ a9	over	7	burglary	8	.916	10	.782	9
$\underline{C}$ a10	proper	2	drunk	10	.968	2	.907	2
$\underline{C}$ b1	over	6	burglary	15	.911	1	.774	1
$\underline{C}$ b2	proper	10	burglary	20	.909	2	.773	2
$\underline{C}$ b3	proper	8	burglary	30	.906	3	.770	3
$\underline{C}$ b4	proper	10	burglary	30	.894	4	.746	4
$\underline{C}$ b5	under	2	suspicious person	10	.887	5	.705	5
$\underline{C}$ b6	under	2	suspicious person	20	.868	8	.678	8
$\underline{C}$ b7	under	8	burglary	5	.881	6	.698	6
$\underline{C}$ b8	under	8	burglary	10	.871	7	.685	7
$\underline{C}$ b9	under	8	burglary	20	.851	9	.657	9
$\underline{C}$ b10	no show	25	cat in tree	70	.587	10	.316	10

attributes of the function that is to be formed are MUFs. That is, in the notation that was introduced earlier. $\underline{C}$ = ($PRECUSTO_i$, $PREPOLO_i$). The relative scaling factors (k_i's) are again assessed using indifference pairs, but the pairs will be the utilities of two-four attribute consequences. The three indifference consequences, and the equivalent utilities that were used are found in Table 6-4. Two attributes were varied, while the other six remained fixed to aid in conceptualizing the tradeoffs that were involved. The scaling constant for $U_{GRANDMUF}(\underline{C}i)$ are

$$k_{PRECUSTO} = .895$$

$$k_{PREPOLO} = .881$$

$$K = -.984$$

$U_{GRANDMUF}(\underline{C}i)$ is multiplicative and compensating, $k_{PRECUSTO} > k_{PREPOLO}$.

Indifference curves could have been computed for the MUF, $U_{GRANDMUF}$; they were not.

E.3.b Evaluation of Alternative for GRANDMUF.

The evaluation of alternatives of GRANDMUF are the last and most important series, because they represent the final performance measure. The procedure followed was the same as with PRECUSTO and PREPOLO. Of the 27 alternatives evaluated 16 are found in Table 6-4.

Table 6-4

EVALUATION OF ALTERNATIVES - OVERALL

	GRANDMUF					ORIGIANL		.5, .5	
	OUT1	TRAV1/ NERV1	OUT2*	ACCU	JOB2	$U_{GRANDMUF}(\underline{C}i)$	ORDER	$U_{GRANDMUF}(\underline{C}i)$	ORDER
$\underline{C}$ a1	convict	2	$\overline{V}$	proper	cat in tree	.997	1	.989	1
$\underline{C}$ a2	convict	15	$\overline{V}$	proper	cat in tree	.991	3	.962	3
$\underline{C}$ a3	convict	5	$\overline{V}$	proper	cat in tree	.990	3	.958	4
$\underline{C}$ a8	too late	15	v	under	buglary	.938	7	.825	7
$\underline{C}$ a9	convict	15	v	proper	burglary	.981	6	.928	6
$\underline{C}$ d1	arrest	6	v	over	burglary	.980	2	.928	2
$\underline{C}$ d4	convict	20	$\overline{V}$	over	suspicious person	.961	6	.835	7
$\underline{C}$ d6	convict	20	v	proper	cat in tree	.969	4	.891	4
$\underline{C}$ d7	too late	20	v	proper	cat in tree	.895	10	.741	9
$\underline{C}$ f1	scare away	12	v	over	suspicious person	.924	7	.8	7
$\underline{C}$ f2	scare away	12	$\overline{V}$	under	suspicious person	.945	6	.81	6
$\underline{C}$ u1	too late	5	$\overline{V}$	proper	cat in tree	.990	1	.962	1
$\underline{C}$ u2	scare away	5	$\overline{V}$	proper	lockout	.984	4	.938	4
$\underline{C}$ u3	arrest	55	$\overline{V}$	proper	vehicle	.983	5	.926	5
$\underline{C}$ u4	scare	55	$\overline{V}$	proper	drunk	.990	1	-	1
$\underline{C}$ u5	arrest	55	$\overline{V}$	proper	suspicious person	.990	1	-	1

* $\overline{V}$ - Not victimized.

v - Victimized.

In general, the rank ordering of the alternatives was not greatly affected between the original weightings which were compensating, and the additive form, at .5, .5 as long as each submuf was weighted nearly equally. The rank ordering of $U_{GRANDMUF}(\underline{C}d2)$ and $U_{GRANDMUF}(\underline{C}d4)$ as well as $U_{GRANDMUF}(\underline{C}d5)$ and $U_{GRANDMUF}(\underline{C}d7)$ switched, but I feel this is a very fine distinction. It will be up to the d.m. to decide if it is significant or not.

Additional insight can be gained by observing the values found in Table 6-5. Here the original form of $U_{GRANDMUF}(\underline{C}i)$ is capable of some nice distinctions, especially between $U_{GRANDMUF}(\underline{C}u3)$ and $U_{GRANDMUF}(\underline{C}a9)$, and $U_{GRANDMUF}(\underline{C}u3)$ and $U_{GRANDMUF}(\underline{C}d1)$. However when $k_{PRECUSTO}$ and $k_{PREPOLO}$ are changed to .5, .5, these rankings reverse, while all others remain the same.

Thus, if the relative scaling factors, and consequently K for $U_{GRANDMUF}(\underline{C}i)$ are changed, the model remains fairly robust. But as we approach .5, .5 we should be aware that certain rank order changes could occur that will be undesirable.

E.3.c <u>Modification to GRANDMUF</u>

At this point, $U_{GRANDMUF}(\underline{C}i)$, as it was originally defined, is a well-behaved, well-defined GMUF that is capable of providing insight into preemptive dispatching. My only objection, again, concerns the small differentiation that exists between some of the consequences where my personal judgement says the differences should be greater. I'd like

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Table 6-5

EVALUATION OF ALTERNATIVES - OVERALL

	GRANDMUF						$U_{GRANDMUF}(\underline{C}_i)$	
	OUT1	TRAV1/ NERV1	OUT2*	TRAV2/ NERV2	ACCU	JOB2	ORIGINAL	.5, .5
u1	too late	5	$\overline{V}$	12	proper	cat in tree	.990	.962
a2	convict	15	$\overline{V}$	10	proper	cat in tree	.991	.962
u3	arrest	5	$\overline{V}$	12	proper	vehicular accident	.983	.926
a9	convict	15	v	15	proper	burglary	.981	.928
a8	too late	15	v	15	under	burglary	.938	.825
d4	convict	20	$\overline{V}$	40	over	suspicious person	.961	.835
f1	scare away	12	v	28	over	suspicious person	.924	.800
f2	scare away	12	$\overline{V}$	40	under	suspicious person	.945	.81
u3	arrest	5	$\overline{V}$	12	proper	vehicular	.983	.926
d1	arrest	6	v	15	over	burglary	.980	.928

* $\overline{V}$ - Not victimized.

v - Victimized.

to demonstrate how the function can be "fine tuned" once the basic structure has been defined.

The technique that will be used have been demonstrated in the previous sensitivity analyses of $U_{PRECUSTO}(\underline{C}i)$ and $U_{GRANDMUF}(\underline{C}i)$. The objective will be to expand the difference between alternatives or increase the sensitivity as was done with $U_{PRECUSTO}(\underline{C}i)$ without destorting the desired ranking, as was demonstrated could happen with $U_{GRANDMUF}(\underline{C}i)$.

The evaluation will be performed using two reasonable point estimates of possible consequences as a crude way to indicate the probable impact of the changes on the respective dispatching strategies. One consequence will be the result of preempting. The eight attributes for alternatives 1 and 2 are found below:

	OUT 1	NERV 1	OUT 2	NERV 2	ACCU	TRAV 1	JOB 2	TRAV 2
ALT 1	scare away	6.68	not victim.	no wait	proper	6.68	cat in tree	no wait
ALT 2	arrest	1.13	not victim.	10.85	proper	1.13	cat in tree	10.85

The spatial relation between busy and free units and the incoming call was taken from the spatial simulation (Chapter VII). In the situation that was chosen, there were three busy nonurgent units located nearer than the closest free units. The closest free unit was found

6.68 minutes from the urgent caller while the closest busy unit was only 1.13 minutes away. Because there was approximately a five minute difference in arrival times, it was felt that the busy unit should do better than the free unit if it were dispatched to the call. Certainly, it should do no worse. Thus it was assumed that the free unit SCARED the suspect AWAY, while the busy unit would ARREST the suspect. In addition it was felt that proper screening was appropriate for each case and that JOB 2 $\equiv$ CAT IN A TREE helped to reduce unnecessary complications. The sensitivity to changes in JOB 2 will be tested later.

As a special note:, I have assumed in the nonpreemptive situation that a "pseudo-preemption" has taken place. In this case all performance measures that relate to a nonurgent customer are set to their best levels.

The information is found in Table 6-6.

The evaluation of $U_{GRANDMUF}(\underline{C}i)$ with all originally defined weights is found in row (1). The spread of .002 seems to be too small considering the suspect is ARRESTed in one situation and only SCARED AWAY in the other. As a result, the k_i's of $U_{PRECUSTO}(\underline{C}i)$ will be multiplied by .7. Now (BIG)K of $U_{PRECUSTO}(\underline{C}i)$ = -.930 which is less compensating. However, prior to evaluating $U_{GRANDMUF}(\underline{C}i)$, the indifference curves with (BIG)K = -.930 should be compared to the original curves to insure the MUF has not

Table 6-6

Fine Tuning

(1) Evaluation of GRANDMUF with all original k_i's and BIG K

$U_{GRANDMUF}(ALT\ 1) = .995$
$U_{GRANDMUF}(ALT\ 2) = .997$ Spread = .002

(2) Alter $U_{PRECUSTO}(\underline{C}i)$; k_i's x .7

$U_{GRANDMUF}(ALT\ 1) = .989$
$U_{GRANDMUF}(ALT\ 2) = .993$ Spread = .004

(3) Alter weights $U_{PRECUSTO}(\underline{C}i)$ and $U_{PREPOLO}(\underline{C}i)$ to .6, .4, respectively

$U_{GRANDMUF}(ALT\ 1) = .952$
$U_{GRANDMUF}(ALT\ 2) = .970$ Spread = .018

(4) Weights remain .6, .4: JOB 2 = family quarrel

$U_{GRANDMUF}(ALT\ 1) = .952$
$U_{GRANDMUF}(ALT\ 2) = .943$

(5) Weights remain .6, .4; JOB 2 = lockout

$U_{GRANDMUF}(ALT\ 1) = .952$
$U_{GRANDMUF}(ALT\ 2) = .948$

(6) Weights remain .6, .4; JOB 2 = suspicious person

$U_{GRANDMUF}(ALT\ 1) = .952$
$U_{GRANDMUF}(ALT\ 2) = .955$

(7) Weights remain .6, .4; U(Victimized) ≡ .3

$U_{GRANDMUF}(ALT\ 1) = .952$
$U_{GRANDMUF}(ALT\ 2) = .930$

(8) Weights remain .6, .4; U(Victimized) ≡ .0

$U_{GRANDMUF}(ALT\ 1) = .952$
$U_{GRANDMUF}(ALT\ 2) = .913$

Table 6-6
(continued)

(9) Weights remain .6, .4; V(Victimized) = .1

$U_{GRANDMUF}$(ALT 1) = .952
$U_{GRANDMUF}$(ALT 2) = .919

(10) Alter relative scaling factors of $U_{GRANDMUF}(\underline{C}i)$ to .781, .893

$U_{GRANDMUF}$(ALT 1) = .987
$U_{GRANDMUF}$(ALT 2) = .992   Spread = .005

(11) Relative scaling factors same as (10); JOB 2 = BURGLARY

$U_{GRANDMUF}$(ALT 1) = .987
$U_{GRANDMUF}$(ALT 2) = .987

been altered inappropriately. Remember the initial sensitivity analysis on $U_{PRECUSTO}$ ($\underline{C}i$) demonstrated that it was rather insensitive to such changes.

Indifference curves were generated through two points for the comparison of (OUT 1 vs NERV 2) and one point for the comparison of (OUT 1 to NERV 1). The results are found below in Table 6-7.

Table 6-7 Indifference Curves - Fine Tuning

INDIFFERENCE CURVE BETWEEN (OUT 1, NERV 2) THROUGH (.6,25)

NEW		OLD
U(.8, 35.708)	~	U(.8, 38.717)
U(.6, 25)	~	U(.6, 25.006)

INDIFFERENCE CURVE BETWEEN (OUT 1, NERV 2) THROUGH (1, 80)

U(.8, 59.993)	~	U(.8, 51.37)
U(.6, 56.483)	~	U(.6, 42.024)
U(.4, 9.993)	~	U(.4, .247)

INDIFFERENCE CURVE BETWEEN (OUT 1, NERV 1) THROUGH (.2, 20)

U(.4, 501)	~	U(.4, 47.343)
U(.1, 15.514)	~	U(.1, 15.592)

The difference between the indifference curves is not unreasonable.

Now the values of $U_{GRANDMUF}$(alt 1), $U_{GRANDMUF}$ (alt 2), with the k_i's of $U_{PRECUSTO}(\underline{C}i)$ multiplied by .7 can be found in row (2). The spread has been increased. The effect changing $U_{PRECUSTO}(\underline{C}i)$ by a factor of .7 has on the evaluation of $U_{PRECUSTO}(\underline{C}i)$ is even more evident in Table 6-8. In the "a" series, $\underline{C}a_2$ and $\underline{C}a_3$ are ranked fourth and third respectively. This distinction was not made under the original evaluation. In the "f", "u" series, the new evaluation is more sensitive than the old. $U_{GRANDMUF}(\underline{C}u1)$, $U_{GRANDMUF}(\underline{C}u4)$, and $U_{GRANDMUF}(\underline{C}u5)$ are no longer the same. In addition $U_{GRANDMUF}(\underline{C}f1)$ and $U_{GRANDMUF}(\underline{C}f2)$ demonstrate that with the (BIG) K of $U_{PRECUSTO}(\underline{C}i)$ decreased, the impact of victimization is truly felt.

Next we will try altering the weighting factors of the SUBMUFS in GRANDMUF to increase the spread between consequences. From the senstivity analysis that was previously performed on $U_{GRANDMUF}(\underline{C}i)$ we know that it is probably better to keep the ratios nearly equal and above .5, .5. However, intuitively, we want to raise the weight of $U_{PRECUSTO}(\underline{C}i)$ at the expense of $U_{PRECUSTO}(\underline{C}i)$ so that the more subjective measures receive more weight.

This will accomplish a number of purposes: (1) the customer will be given consideration over the server, (2) specifically, JOB 2 in $U_{PRECUSTO}(\underline{C}i)$ will be given less emphasis while the importance of arrest and a quick response is accentuated, (3) both submufs will be made less

compensating so that the differentiation between consequences is accentuated.

The results are found in row (3). When the weights are .6 and .4, the spread increases to .018.

It is interesting to see just how important the level of JOB 2 is to $U_{GRANDMUF}(\underline{C}i)$, even with the weightings at .6, .4. The results are shown on rows (4), (5) and (6). If JOB 2 is a SUSPICIOUS PERSON, BURGLARY, DRUNK or a CAT IN A TREE, preemption will be better than non-preemption (with regard to the reference points used).

Another interesting evaluation recognizes the influence of victimization on $U_{GRANDMUF}(\underline{C}i)$. In rows (7), (8), (9) $U_{out\ 2}$(VICTIMIZATION) is varied and the differences of the spread are noted. If the customer doesn't find being VICTIMIZED "too bad," the utility of preemption when victimization occurs can be raised, perhaps significantly, even though the probability of occurrence is small.

The final evaluation involves making the weights of the submufs agree with the altered values of PRECUSTO. The method is the same that was used when the original values were obtained. In fact, the same indifference points were used. The new weights are:

$$k_{PRECUSTO} = .781$$

$$k_{PREPOLO} = .893$$

$$\text{BIG } K_{GRANDMUF} = -.967$$

The function is less compensating than the original. Row (10) shows that the spread has indeed increased. Row (11) shows that because more emphasis is placed on JOB 2 now, than when the weights were .6, .4, preemption does not become better than non-preemption until JOB 2 is a BURGLARY.

Table 6-8

EVALUATION OF ALTERNATIVES

	GRANDMUF ATTRIBUTES	PRECUSTO x .7		ORIGINAL	.5, .5
		$U_{GRANDMUF}(\underline{C}i)$	ORDER	ORDER	ORDER
$\underline{C}$ f1	Found in Table 5-4	.726	7	7	
$\underline{C}$ f2		.764	6	6	
$\underline{C}$ u1		.919	3	1	
$\underline{C}$ u2		.905	4	4	
$\underline{C}$ u3		.908	5	5	
$\underline{C}$ u4		.929	2	1	
$\underline{C}$ u5		.939	1	1	
$\underline{C}$ a1		.979	1	1	1
$\underline{C}$ a2		.937	4	4	3
$\underline{C}$ a3		.942	3	3	4
$\underline{C}$ a4		.955	2	2	2
$\underline{C}$ a5		.082	10	10	10
$\underline{C}$ a6		.543	9	9	9
$\underline{C}$ a7		.586	8	8	8
$\underline{C}$ a8		.752	7	7	7
$\underline{C}$ a9		.864	6	6	6
$\underline{C}$ a10		.927	5	5	5

VII. SPATIAL SIMULATIONS

A. Introduction

The spatial model defines the spatial conditions that must be met before a situation can be described as "preemptable". Specifically, a busy unit must be located closer than the closest free unit such that a preemptable area exists. By definition, this means $D_f - D_b \geq D_c$. Then there must be a least one free unit located in this preemptable area to act as a replacement unit for the preempted customer. If there is more than one free unit in the area, the closest will be chosen as the replacement unit. A situation is defined to be "preemptable" if all these conditions are met.

But the spatial model is still only intuitive. It has not been evaluated. A realistic situation must be simulated to determine the applicability of the model, and its consequences.

The spatial model is valuable because it not only defines preemption but it allows us to determine performance measures such as the mean distances to the closest nonurgent busy, free or replacement units. It can be used to compute the preemptable area and the probability that there is at least one free unit in that area. However, although these measures provide useful insight into preemption, they only provide an aggregate impression of what preemption can do and we found there are limits to the measures we can readily compute because we needed the computer to determine the probability of preemption.

There are many other distinctions that must be evaluated to properly investigate preemption. For instance, preemption is not only a question of a unit's spatial positioning, but also the type job the unit is assigned and the type call that is received. A means is needed to describe the many situations and subsequent tradeoffs that occur. A simulation can provide the additional flexibility we are seeking.

A simulation can provide us with an approximation of the earlier measures we have evaluated, and it will allow us to vary parameters such as the type job a unit is assigned, and to determine the probability of preemption.

There are a number of questions that must be explored:

(1) What is a reasonable cost curve? That is, how should the preemptable area vary with the difference between the distance to the closest free and the closest busy unit and how will this affect the probability of a free unit being located in the preemptable area, and consequently the probability of preemption?

(2) What is the mean number of busy units that might be expected to be closer than the closest free unit?

(3) What is the mean distance to the closest free, busy and replacement unit?

(4) How do all the above vary with different utilization ratios?

The simulation can be broken down into two tasks: (1) Generating a spatial picture and (2) Evaluating a situation according to preemptive criteria. The objective is to simulate the information that would be

available to a police response system with AVM, and the output that could be provided by CAD.

B. Generation of Spatial Picture

The information that is pertinent is (1) unit locations, (2) unit status, and (3) call locations. With this data, the spatial preemptive constraints can be checked.

Remembering that an $M/G/\infty$ queuing model has been chosen, we know that calls are arriving in a spatially Poisson manner, and that the units which are servicing these calls will be positioned similarly. Free units are also distributed in a spatially Poisson, due to random patrol.

But for a Poisson process, if there are exactly N arrivals in (0, X), the unordered arrivals in space are uniformly, independently distributed over the interval, (0, X). (See Karlin pp. 183-184).[60] Thus we can use a random number generator that uniformly selects numbers between 0 to 1 to provide X and Y coordinates of both busy and free unit locations. The positions can eventually be scaled from a unit area to the dimensions of the area that is chosen.

Similarly, a third random number, call it Z, can be generated for each X, Y pair to determine unit status. The interval 0 and 1 can be subdivided into three subintervals whose length corresponds to the probability of being either an urgent busy unit, or a nonurgent busy unit, or free. Consequently, any number of unit locations and their statuses can be easily generated.

The next issue is what parameter values for λ_1, λ_2, υ_1, υ_2, A and N should be chosen so that the M/G/∞ approximation is valid. It was assumed that the city's area (A) would be 10 miles by 10 miles. The number of servers (N) would be 100. The mean service time for priority one and priority two incidents would be equal, $1/u_1 \equiv 1/u_2 \equiv 30$ mins or 1/2 hour per call. That is two calls per hour could be serviced per unit. The condition that must be met is that the probability of all services being busy is insignificant, say less than one percent. It is possible to use the central limit theorem to approximate the probability of saturation, that is, that all 100 units are busy. (See Table 7-1)

The probability that a unit is either busy or free can be described by a Bernoulli process. If we define r to be the number of busy servers then r is equal to the sum of a number of independent, identically distributed random variables, X, that are equal to 0 if the unit is free and 1 if it is busy.

Thus as $r \to \infty$ the CDF $P_{r \leq}(r_0)$ approaches the CDF of a Gaussian random variable.

By definition,

$$\text{Prob } (a \leq r \leq b) \simeq \Phi\left[\frac{b-E(r)}{\sigma r}\right] - \Phi\left[\frac{a-E(r)}{\sigma r}\right]$$

$$E(r) = nP$$

$$\sigma r = \sqrt{nP(1-P)} \qquad \text{where } n = N = 100$$

$$P=\rho$$

Table 7-1

SPATIAL MODEL PARAMETER TABLE

	AREA	A	$= 100mi^2$ $(10x10mi^2)$		
1.	NUMBER OF SERVERS	N	$= 100$		
2.	SERVICE RATE/mi^2	$\mu_{1,2}$	$= 2$ calls/hr $\left(\equiv \frac{.02\text{calls}}{mi^2}/hr\right.$		
			1	2	3
3.	URGENT ARRIVAL RATE/mi^2	λ_1	$= \frac{.06\text{calls}}{mi^2}/hr$	$\frac{.04\text{calls}}{mi^2}/hr$	$\frac{.02\text{calls}}{mi^2}/hr$
4.	NONURGENT ARRIVAL RATE /mi^2	λ_2	$= \frac{1.44\text{calls}}{mi^2}/hr$	$\frac{.9\text{calls}}{mi^2}/hr$	$\frac{.48\text{calls}}{mi^2}/hr$
5.	URGENT UTILIZATION	ρ_1	$= .03$	.02	.01
6.	NONURGENT UTILIZATION	ρ_2	$= .72$	.45	.24
7.	AVAILABILITY	ρ_{free}	$= .25$	.53	.75
8.	HI-VELOCITY	V_1	$= 15mph \equiv 4mins/mile$		
9.	LOW-VELOCITY	V_2	$= 10mph \equiv 6mins/mile$		

We want to know the probability that $0 \leq r \leq 99$. Because we intend to use ρ as great as .75 we will check $\rho=.8$ to see if the probability of saturation is insignificant.

$$E(r) = n\rho = 80$$

$$\sigma r = 4$$

Thus, $\Phi[\frac{99-80}{4}] - \Phi[\frac{0-80}{4}]$

$$\Phi[\frac{20}{4}] - \Phi[-20] = \Phi[\frac{19}{4}] - [1-\Phi(20] \simeq 0$$

Thus, the probability of all 100 units being busy simultaneously is insignificant and a spatially oriented $M/G/\infty$ queuing model is a reasonable estimate to be used as long as $\rho < .8$.

Given a value of ρ, λ can be determined for a multi-server queuing system by solving equation, $\rho = \frac{\lambda}{\mu N}$

Consequently, we can now generate a "picture" of a particular spatial orientation of one hundred free and busy servers. Once a call location is known, the necessary constraints from the preemptive model can be evaluated.

Five call locations were provided for each "picture". Their locations were at (.25, .25), (.5, .5), (.75, .75), (.25, .25), (.75, .75). Twenty pictures were generated. Thus 100 separate "snapshots" were

evaluated. The values of ρ were altered such that 35 snapshots were evaluated for ρ = .25, 30 snapshots were evaluated for ρ = .53, and 35 snapshots were evaluated for ρ = .75.

The cost curves that were used were constructed arbitrarily by the author. Only a few simple assumptions were necessary. The first assumption concerned the minimum meaningful difference between D_f and D_b that it was felt had to exist before preemption would be considered. It was assumed that if the difference in travel time was less than 30 seconds, or 1/8 mile at 15 miles per hour, it was not worthwhile to preempt. Thus, referring to Figure 3-4 , the two curves must intersect at a distance of 1/8 mile. Next, the slopes of the curves had to be chosen. The reasonableness of the relationship between the curves will be reflected in the magnitude of the maximum preemptable radius (which will also affect the probability of preemption). The slopes were chosen such that with a difference of 3 miles between D_f and D_b a preemptable radius of 5.84 miles resulted. The results of the simulation showed that the preemptable radius exceeded the city boundaries infrequently with the call locations at the positions that were indicated.

C. Program Used to Determine Spatial "Preemptability"

To simplify the mathematics, the spatial model that will be used is in Euclidean distances. A diagram of the model [with the notation that was used for the computer program found in Appendix E] is found in

Figure 7-1 . The procedure was quite simple. Unit locations are stored in arrays according to their priority.

$\begin{pmatrix} X0(I) \\ Y0(I) \end{pmatrix} \equiv$ free unit, $\begin{pmatrix} X1(I) \\ Y1(I) \end{pmatrix} \equiv$ urgent busy unit,

$\begin{pmatrix} X2(I) \\ Y2(I) \end{pmatrix} \equiv$ nonurgent busy unit.

When a call is received at location (CLX, CLY), the computer determines the distance to the closest free unit (SMFIN) and then determines if there are any busy priority two units located nearer than the closest free unit, and stores these locations (DPRE (I)). Then the program checks the location of all free units (stored in array XO (I)) to see if they be outside of the closest free unit perimeter, but inside the maximum preemptable radius perimeter associated with the busy nonurgent unit being investigated. Any free units that meet these conditions lie in the preemptable area and their distances to the preempted customer are stored (in (DBUFR (I)). [Note - no edge effect is possible because free unit poisitions are not generated outside the defined area.] Then it is a simple process to compile the appropriate data.

D. Results

There were three utilization ratios used in the evaluations:

$\rho\ 1 = .75$

$\rho\ 2 = .53$

$\rho\ 3 = .25$

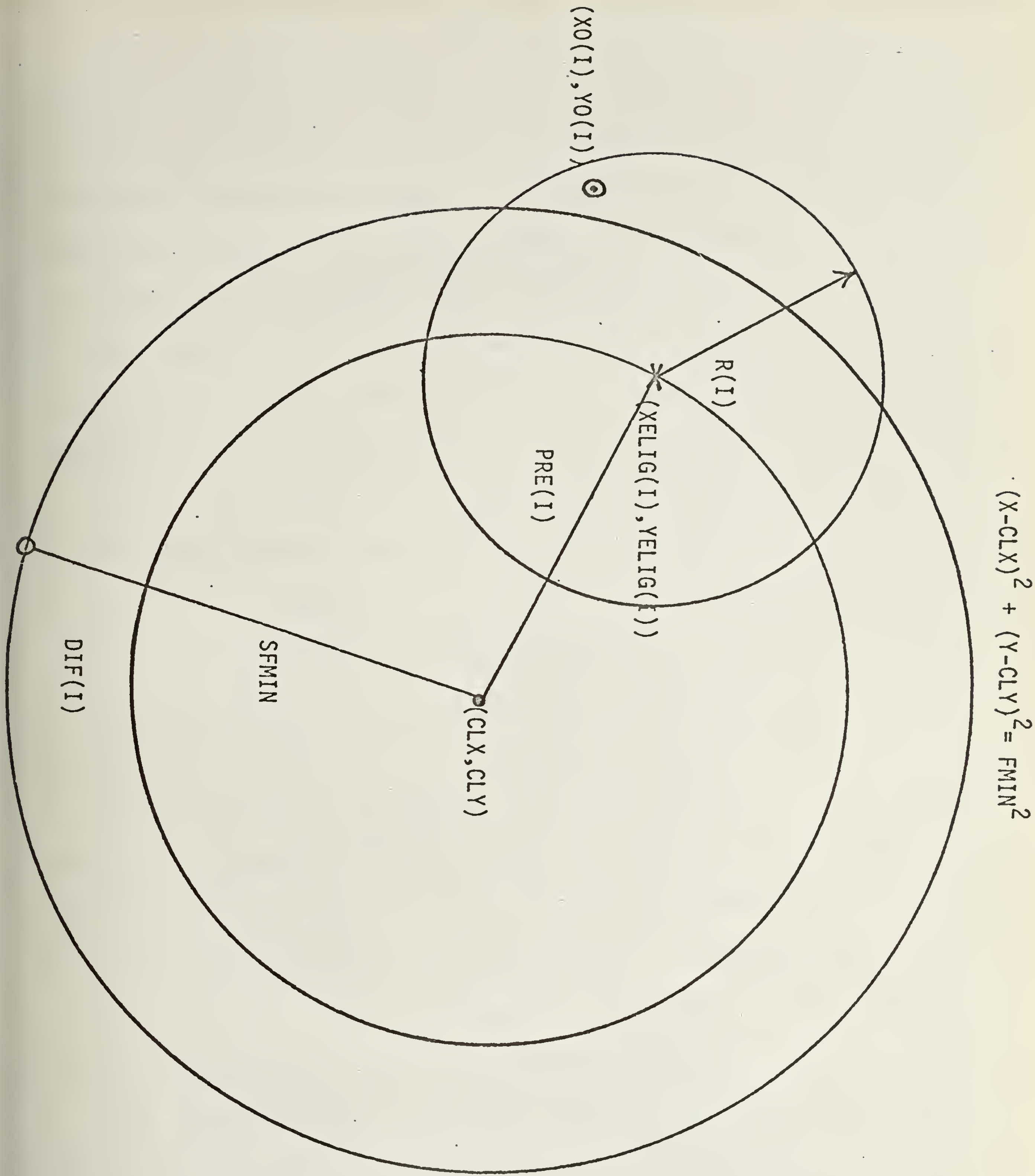


Figure 7-1 Spatial Model in Euclidean Distances with the Notation Used in the Spatial Simulation Program.

Data was compiled as a function of the specific ρ's. It should be mentioned that as ρ increases the number of busy units per unit area also increases. Thus, the likelihood of first reaching a busy unit, when departing from any point, is greater than the likelihood of first reaching a free unit. Conversely, the distance to a free unit is probably greater than the distance to a busy unit. These intuitive effects of varying ρ will be noted in the data to follow.

(1) The probability that at least one busy nonurgent unit was located nearer than the closest free unit:

1	29/35	It is seen that as ρ increases
2	14/30	the probability of a busy non-
3	6/35	urgent unit being found nearer
		the closest free unit increases.

(2) P [at least one nonurgent busy unit is nearer than the closest free unit such that preemptable area exists. In this case $D_f - D_b \geq D_c$].

1	22/35	When the minimum separation
2	11/30	constraint, D_c, is applied many
3	5/35	"possible preemptable situations"
		are excluded.

(3) Average number of nonurgent busy units that are closer than the closest free unit are:

1	2.485	122/35	Again it is not unreasonable
2	1.466	44/30	to find that there are more
3	.2571	9/35	nonurgent busy units found
			nearer than the closest free
			unit with increasing ρ.

(4) Mean distance to closest busy unit is:

1	.7047	The mean distance to the
2	.9922	closest nonurgent busy unit
3	1.316	decreases as ρ increases.

(5) Mean distance to closest free:

1	1.3598	The mean distance to
2	.9607	the closest free unit
3	.5088	increases as ρ increases.

(6) The number of spatially "preemptable: "situations" is simply the number of snapshots where a preemptable area existed and at least one free unit was in it.

1	13/35
2	9/30
3	1/35

This is logical because there is more chance of a busy unit being located closer than a free unit as the utilization increases.

(7) The probability that when at least one nonurgent busy unit is nearer than the closest free unit that a "snapshot" is a preemptable situation is:

1	13/29	.44	It is interesting
2	9/14	.64	that at this point
3	1/6	.16	given that there is

at least one busy unit closer that the closest free unit, it is more likely that the situation is preemptable, when $\rho = .53$, than when $\rho = .75$.

(8) P [a busy unit that is located closer than the closest free unit is preemptable.]

1	45/122	.36	The ordering remains
2	21/44	.47	the same as in (7)
3	1/9	.11	but all values are

reduced. This makes sense because each unit should have less chance than the whole snapshot.

(9) Mean distance to the closest replacement unit.

1	.157	It is logical that as ρ decreases
2	1.196	and there are more free units the
3	1.1	distance to the closest free unit
		decreases.

(10) Mean time saved to the urgent customer given that a preemptable area exists.

(Case 2)

$w/v_1 = 15$ mph

1 2.936 mins.

2 2.677 mins.

3 1.862 mins.

The above results can be found in Table 7-2.

Table 7-2

SPATIAL SUMMARY

1. $\rho_b = .75$ 2. $\rho_b = .47$ 3. $\rho_b = .25$

where $\rho_b = \rho_1 + \rho_2$

MEAN DISTANCE TO CLOSEST BUSY (miles)

	Predicted	Actual*
1	.5892	.7047
2	.7453	.9922
3	1.020	1.316

*(remember small sample size was use.)

MEAN DISTANCE TO CLOSEST FREE (miles)

	Predicted	Actual
1	1.00	1.3598
2	.6868	.9607
3	.5773	.5088

	PROB $[r \leq 100]$
1	.9973
2	1.0
3	1.0

	PROB $[f - b < tc] = 1 - \dfrac{\rho_f}{\rho_f + \rho_b}$
1	.7428
2	.4592
3	.2425

PROB [n closer than closest free] = $\left(\dfrac{\rho_f}{\rho_2 \ \rho_f}\right)\left(\dfrac{\rho_f}{\rho_2+\rho_f}\right)^n$ = (see Appendix B)

		n = 1	2	3	4	5	6	8	9	10	16
.72 =	1	.1912	.1419	.1053	.0781	.0580	.0430	.0239	.0176	.0130	.0021
.45 -	2	.2482	.1139	.15	.0240	.0110	.005				
.24 =	3	.1836	.0445	.0107	.003						

Table 7-2 (continued)

	Predicted	Actual
MEAN NUMBER OF BUSY CLOSER THAN CLOSEST FREE		
1		3.489
2		1.466
3		.2561
P[A GIVEN SNAPSHOT IS PREEMPTABLE]		
1	.3714	
2	.30	
3	.02857 (1 data point)	
P[A SNAPSHOT WHERE A BUSY IS CLOSER THAN THE CLOSEST FREE] IS PREEMPTABLE		
1	.4482	
2	.6428	
3	.1666	
P[BUSY UNIT CLOSER THAN THE CLOSEST FREE IS PREEMPTABLE]		
1	.3688	
2	.4722	
3	.1111	
MEAN DISTANCE TO CLOSEST REPLACEMENT (MILES)		
1	1.57	
2	1.196	
3	1.1	

VIII. EVALUATION

A. Procedure

Once the spatial model is defined and utilized in the spatial simulation, the modified decision tree is formulated, and GRANDMUF has been created, it is possible to simulate the operation of a programmed preemptive dispatching algorithm.

The process would proceed as follows:

1. An urgent call is received at location (CLX,CLY)

2. The spatial model, as it is used in the spatial simulation, compares the relative (Euclidean) positions of all busy nonurgent (X2(I)) units and free (X0(I)) units to this incoming call. It then computes:

   (a) the distance to the closest free unit (SFMIN)

   (b) the distance to each pri 2 busy unit that is located closer than the closest free unit such that a preemptable area exists (DPRE(I))

   (c) the distance to any replacement units (DBUFR(I)), if they exist.

3. Then all pertinent distances are converted to time using a speed of 4 mins/mile for urgent calls and 6 mins/mile for nonurgent calls.

4. The times become ordinates for determining the utilities of

the single attribute utility functions U_{out1}(OUT 1), $U_{nerv\ 1}$(NERV 1), $U_{nerv\ 2}$(NERV 2), $U_{trav\ 1}$(TRAV 1), $U_{trav\ 2}$(TRAV 2), and also for determining the probability of occurrence of the individual attributes of OUT 1.

5. Once the single utilities are known a separate subprogram can be utilized to compute the utility of any alternative consequence. The form will be multiplicative (see Appendix F). The values for the weighting constants were evaluated for $U_{GRANDMUF}(\underline{C}i)$. It is important to remember that there are twenty (20) alternatives for a preemptive decision and ten (10) for a non preemptive choice in the preemptive dispatching strategy (see Figure 8-1).

6. Now the computor can associate the information contained in the modified decision tree with the appropriate alternatives to compute the expected utility of a preemptive decision and a non-preemptive decision.

7. If the expected utility of preemption is greater than not preempting, that unit would be suggested for preempting.

8. The computer will display a number of busy units, perhaps up to three, for preemption in order of their expected utilities, along with the identity of the corresponding replacement units; and the closest free unit. The dispatcher makes the ultimate decision concerning which unit is dispatched.

B. Results

The particular example that was chosen received a call at grid location (7.5 miles, 7.5 miles) on a 10 by 10 mile grid network.

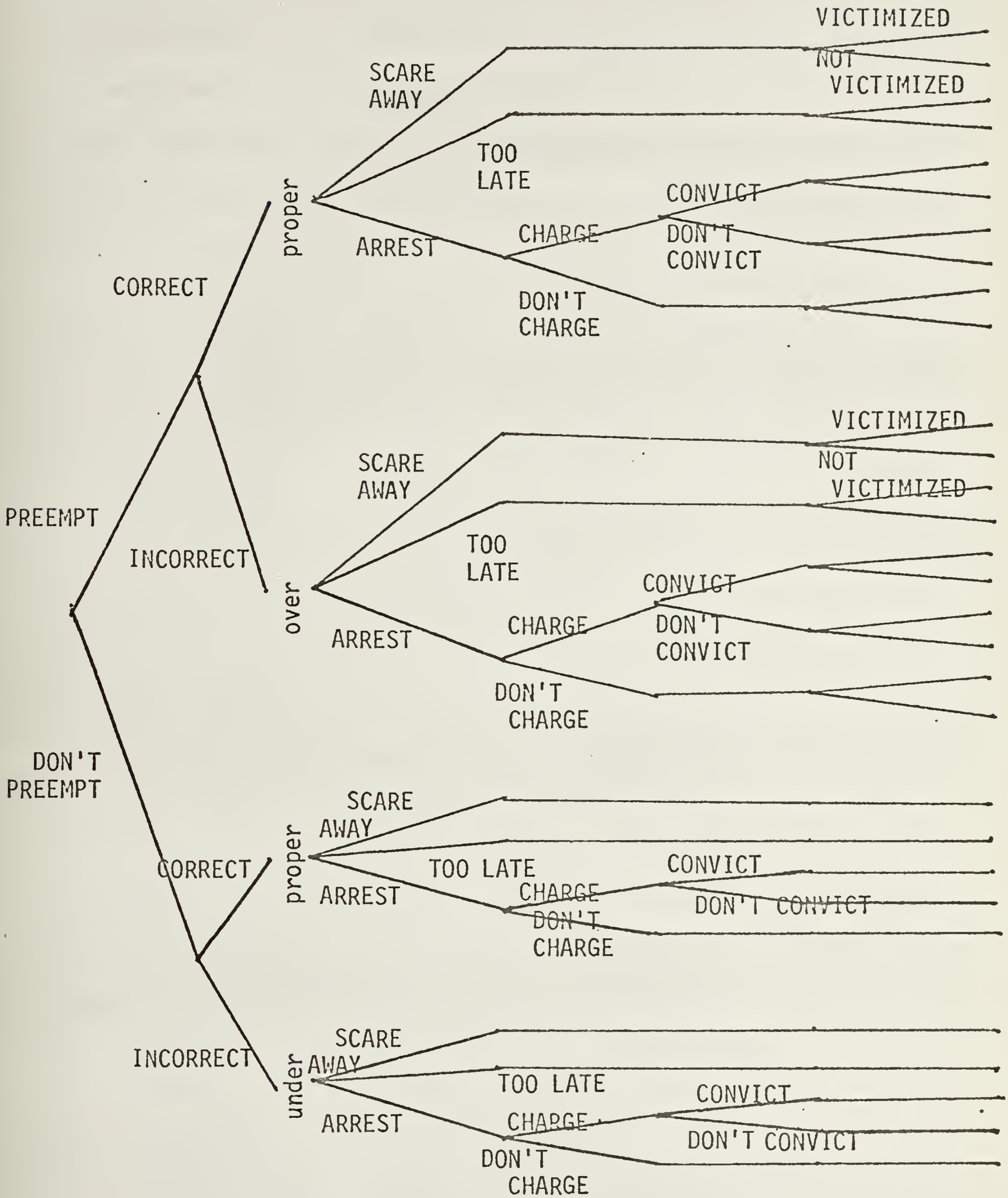


Figure 8-1 Possible Outcomes for a Preemptive Dispatching Strategy

Utilization was .47. The weighting factors for GRANDMUF were the last set determined. Big $K_{GRANDMUF} = \underline{-.967}$, $K_{precusto} = \underline{.781}$, $K_{prepolo} =$ $\underline{.893}$. Three busy units with preemptable areas and eligible replacement units were found. Their distances and equivalent times from the call are recorded below.

	Miles	Minutes
b1	.283	1.13
b2	.7279	2.91
b3	.4009	1.60
f	1.670	6.65

The associated closest replacement units were at:

b1	1.809	10.85
b2	1.672	10.32
b3	1.906	11.436

The probabilities and utilities for each alternative were computed, then the expected utilities of choosing to preempt or not preempt were computed.

$EU(\underline{C}b1)$	.9858
$EU(\underline{C}b2)$	.9537
$IU(\underline{C}b3)$	.9658
$IU(\underline{C}f)$	.9879

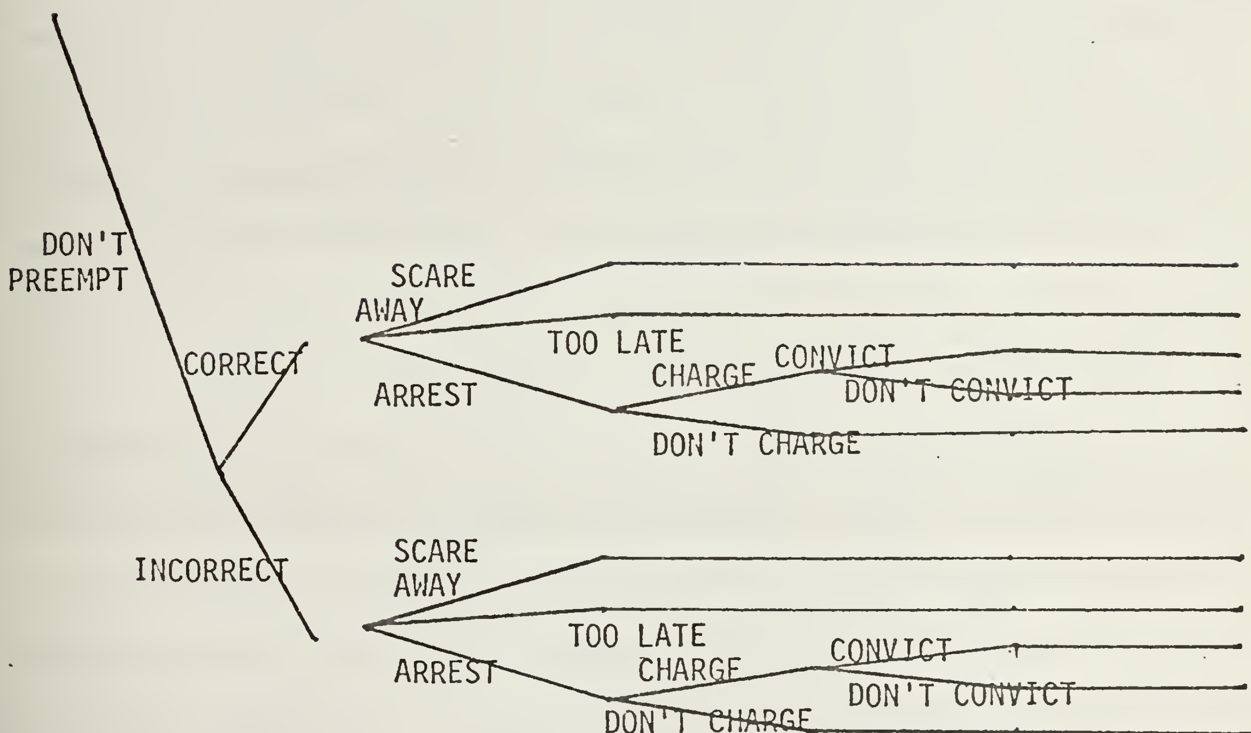
In this example, with the utilities that have been assessed, the preemptive programming algorithm would tell the dispatcher that the best unit to dispatch would be the closest free unit.

There is a great deal of additional numerical analyses that could be done to explore the preemptive dispatching strategy further, but the source and nature of the data used does not justify drawing any more specific numerical conclusions.

Nonetheless, it is possible to not only evaluate the best decision under a preemptive dispatching strategy but also to compare a preemptive (see Figure 8-1) and non-preemptive strategy (see Figure 8-2).

By noting that in the preemptive dispatching strategy that the closest free unit is dispatched anytime the dispatcher cannot preempt, it is obvious that the non-preemptive strategy is the default case for the preemptive strategy. Thus while preemption may not always be the best decision, over the aggregate, the preemptive dispatching strategy must be better with regard to the model as it is defined.

Figure 8-2 Non-preemptive Dispatching Strategy (Non-priority Discipline)



IX. AGGREGATE CONSIDERATIONS

A. Introduction

Now that a preemptive dispatching strategy has been defined and a structure has been described that can be used to evaluate and implement this strategy, it is necessary to step back and shift our attention from the specific dispatching strategy, to the system in which this strategy will be expected to work. It is important to maintain a perspective of how the specific strategy that is being proposed fits into the existing system. We must remember that besides the direct consequences of preemption that can be measured by counting the number of new arrests, or the additional member of minutes a nonurgent customer must wait for service, there is also an aggregate effect due to the misclassification of a call's urgency that affects more than the individual who is directly involved in an incident. The relative frequency of OVER and UNDER responses has significant implications regarding a strategy's effectiveness. In addition, a preemptive dispatching stragegy's success is not only dependent on the accuracy of prioritization but also the policemen - how they perform their jobs and their attitudes, and the public.

This chapter will attempt to briefly draw attention to the "system perspective" of preemption. The model of a preemptive dispatching strategy that was developed in this paper was not specifically oriented toward this perspective, and it is extremely important that aggregate

concerns are not overlooked.

B. Error

It should be recognized that a new method, or dispatching strategy, may create more error and more harmful effects than benefits. Consequently the possibility of increased error must be recognized and analyzed to learn its effect on the success of the strategy.

Preemption clearly creates more opportunities for error. Each new judgement increases the chance of error. Prioritization is the primary source of possible error. Not only is there the chance that a call is a prank or a wrong address, as with all calls, but also the dispatcher can now misclassify a call. As a result, in all cases, the error can be "magnified" because service is a function of call classification. (This will be discussed in greater detail in the next section.) Also, there is the chance that once the policeman leaves, the preempted incident escalates into a serious situation. It would be hard for the police to justify preemption in these situations.

Dispatching a unit that is en route is another source of possible error. The problem is that the police do not really know what type job they are being called on to help with, until they arrive on the scene. If a unit is preempted before it arrives, there is technically no interruption, but there is the possibility that the call may be urgent rather than nonurgent.

One way to minimize error will be to obtain the best current

information prior to making a decision. For instance, before preempting a customer, check with the policemen on the scene to see if they feel they can leave. In most situations this should be the most effective way to reduce the probability of unwanted escalations.

C. Accuracy

In fact, the accuracy of prioritization that the system is capable of rendering is an aspect of a preemptive dispatching strategy that deserves special attention. It must not be overlooked because preemption has been proposed as a means to improve system efficiency. Consequently, the preemptive strategy's effectiveness is highly dependent on its ability to properly categorize incoming calls. Inaccurate prioritization can degrade system performance to the extent that service under a preemptive strategy is worse than if a FCFS strategy was employed.

For this reason measures of the effects of error have been included in the structure of the model and the performance measures. An indirect measure of the effect of the accuracy of prioritization is reflected in the outcome of service received by the priority one customer. If a call that is eligible for preemption is not preempted, a free unit is dispatched from a further distance than was necessary. Consequently, the probability of arrest is reduced and the system is penalized. The utility function ACCU provides a more direct unforgiving measure of the

accuracy of prioritization. Service is considered to be degraded any time an improper response is made. In addition the decision tree probabilistically accounts for improper decisions in the evaluation of any strategy.

Recognizing the potential error that is involved, the dispatching strategy has been chosen to reduce the effects of improper priorization. Of course, there is no queue for the urgent customer and the $M/G/\infty$ queuing model permits us to assume that all interrupted customers are immediately assigned a replacement unit. Consequently, the only extra delay the nonurgent customer experiences is the period of time it takes the replacement unit to arrive on the scene. Furthermore, if a call is classified as nonurgent, or has been classified as urgent and the dispatcher decides not to preempt, they will always be served by the closest free server. The default option of the proposed strategy is a FCFS discipline.

Nevertheless, there are two problems with this approach:

(1) The proposed model only evaluates separate incidents - one at a time. It cannot be used in its present form to determine the effects of preemption on aggregate system performance.

(2) In practice, queues do exist for the nonurgent customer.

A simple single server queuing model which has Poisson arrivals and Poisson-distributed service times (M/M/1) can be used to illustrate the effect of preemption, in a two priority system,on the waiting

times of urgent and nonurgent customers. From Saaty[61] we know that if

$$\lambda_1 = \lambda_2 = \lambda$$

$$\mu_1 = \mu_2 = \mu$$

$$\text{and } \lambda/\mu = \rho$$

then for a preemptive priority dispatching strategy the wait for the urgent customer equals,

$$W_1 = \frac{1}{\mu(1-\rho)}$$

and the wait for the nonurgent customer equals,

$$W_2 = \frac{1}{\mu(1-\rho)(1-2\rho)}$$

while the wait in a no priority system equals

$$W_1 = W_2 = W = \frac{1}{\mu(1-2\rho)}$$

If we graph these waiting times as a function of ρ, it can be seen that the waiting time for the nonurgent customer is longer than that he would have experienced under a nonpriority dispatching strategy, while the urgent customer's wait is reduced. The effect of inaccurate prioritization is now evident.

There are two errors that can occur:

(1) A call that is nonurgent may be processed as an urgent call. This will be defined as an "over" response.

(2) A call that is urgent may be processed as a nonurgent call. This will be defined as an "under" response.

When looking at individual cases, an over response implies that a customer receives more rapid attention than the urgency of his situation warrants. This is certainly not detrimental to him as an individual. On the other hand, an under response means that the customer is receiving service slower than he would have had the strategy been a nonpriority service discipline. In this situation, the individual urgent customer is penalized.

In the aggregate, with regard to efficient system operation, screening inaccuracy can have additional detrimental effects. If there are many over responses, it is likely that this will affect the system's capability to respond appropriately to a properly classified urgent customer, because many of the units will be assigned to urgent incidents. In addition, nonurgent delay will be increased. A disproportionate number of under responses may even be of more critical concern, because urgent customers will be receiving slower service than under the former strategy. The consequences could be catastrophic.

An analysis of "screening" error has been performed by Stevenson and Willemain for priority queuing in emergency services. They have investigated how the appropriateness of a dispatching stragey varies with the systems "screening" accuracy. Analysis of this nature is considered necessary for a preemptive dispatching strategy, as well, to understand when the policy will be most useful. Certainly, screening accuracy is as important a concern as communication delays in initially determining the feasibility of preemption.

However, as a first-cut at a means to evaluate the aggregate effects of screening we might use the following approach. From the tree structure of Chapter Three, under a preemptive dispatching strategy the probabilities of PROPER, OVER and UNDER RESPONSES would appear as shown below. (Figure 9-1)

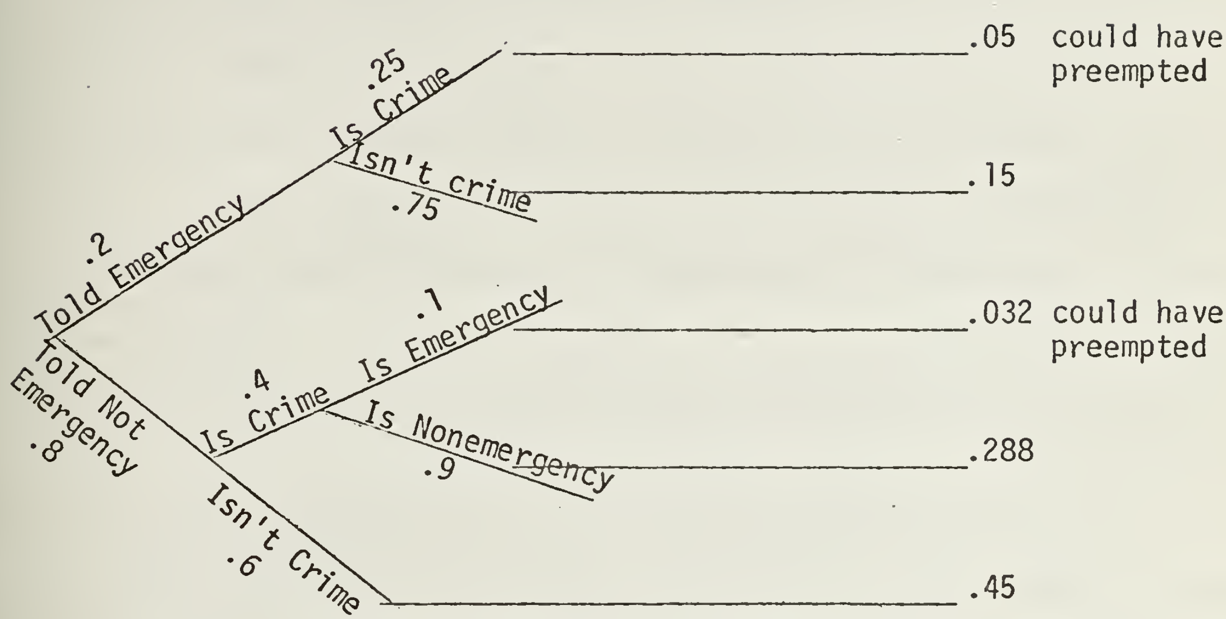
	PROPER	IMPROPER
PREEMPT	.2632	.7368 (over)
DON'T PREEMPT	.9782	.0218 (under)

Figure 9-1

Under a <u>non</u>preemptive strategy, however, a free unit is always dispatched so that the only time an "error" occurs is when there is an emergency call. In every case, the system that is using a nonpriority strategy will "under respond" to an urgent call when its service is compared to a (preemptive) priority strategy.

Thus from the tree below (Figure 9-2)

Figure 9-2



The probabilities of PROPER and UNDER response can be determined.

They are shown in Figure 9-3.

Figure 9-3

	PROPER	IMPROPER
PREEMPT	______	______
DON'T PREEMPT	.918	.082 UNDER

Comparing Figures 9 - 2 and 9 - 3 , we can see that although under a preemptive dispatching strategy there is 73.68 percent more OVER response when a decision is made to preempt, than under a nonpreemptive strategy, under the preemptive strategy there is approximately 6 percent <u>less</u> UNDER response when the decision is not to preempt. Of course, this is a crude aggregate evaluation of the effects of preemption, but it does give some indication of the benefits one might expect to derive from employing a preemptive strategy. It is up to the decision maker to decide how important OVER and UNDER responses are, and the impact they have on the service he can provide.

D. <u>Indication of the Impact of Preemption on the Number of Arrests</u>

The new screening criteria for preemptive dispatching will include incidents where a crime is in progress or suspect on the scene. (See Table 9 - 1). Thus, as an upper bound, it can be assumed that there will be a most 112 new high priority calls. This represents 2.55% of all calls. Using spatial summary statistics (Table 7-2), .30 - .37 of all situations meet the spatial constraints (ρ = .47-.75). Thus between 33.6 and 41.4 calls remain eligible. This figure is then reduced by the probability a unit is agreeable. As a conservative estimate the probability will be set at .5. Now 16.8 - 20.72 or from 17 - 21 of the original 112 calls remain eligible for preemption. Assuming the same clearance rate as emergencies, although with reduced response time the rate should be higher, 6 - 7 new arrests should result. Six new arrests

Table 9-1

NONEMERGENCY DISPATCHING PROBLEM CALLS: BREAKDOWN OF TYPES OF CASES

	FROM CALL INFORMATION								
	APPEARED TO BE "SUSPECT-ON-SCENE"(57)			APPEARED TO BE "POSSIBLE CRIME"(55)			TOTALS(112)		
	AT ARRIVAL:			AT ARRIVAL:			AT ARRIVAL:		
TYPE OF CRIME	TAKE REPORT	SUSPECT GONE	SUSPECT ON-SCENE	TAKE REPORT	SUSPECT GONE	SUSPECT ON-SCENE	TAKE REPORT	SUSPECT GONE	SUSPECT ON-SCENE
MURDER	-	-	-	-	-	1	-	-	1
AGGRAVATED ASSAULT	3	1	-	1	-	-	4	1	-
SEX OFFENSE	-	1	-	-	-	-	-	1	-
BURGLARY	12	6	2	8	1	-	20	7	2
ROBBERY	1	1	-	1	-	-	2	1	-
GRAND THEFT	2	-	-	-	-	-	2	-	-
PETTY THEFT	3	3	-	1	-	2	4	3	2
GRAND THEFT - AUTO	-	-	-	6	-	-	6	-	-
SIMPLE ASSAULT	-	-	-	-	-	1	-	-	1
MALICIOUS MISCHIEF	4	4	1	23	2	-	27	6	1
OTHER	2	2	1	2	2	3	4	4	4
UNKNOWN[1]	-	-	8	-	-	1	-	-	9
TOTAL	27	18	12	42	5	8	69	23	20

[1]Type of crime omitted in data collected.

Source: Science and Technology, p. 94.

compared to 230 + 63 = 293 regular arrests represents an increase of 2.04%.

As far as the actual increase of calls that require emergency service, now 724/4376 or 16.54% of all calls are emergencies. The percent of actual emergencies is 179/4376 = 4.09%. Under the new "in progress" criteria $\frac{724 + 112}{4376}$ or 5.23% will be evaluated as actual emergencies when the patrolmen arrive on the scene.

E. Effects of Preemption on Mean Service Time

With an upper bound of 112 additional preempting calls, only 17 - 21 calls will actually be preempted. It is valuable to determine the effect of these preemptions on the mean service time of the nonurgent/nonemergency customer. This will affect at most 21/(3378 - 112) = (.6429%) of all the entrees.

Each of these will have a mean service time added on equivalent to the time to travel the mean replacement distance -r . When ρ = .47, r = 1.57 miles. At ρ =.75, r = 1.196 miles. So, at 10 mph for ρ between .47 and .75 the replacement travel time is between 7.2 and 9 minutes.

Because the Expected value of a sum is equal to the sum of the expected values, the mean nonurgent service time with preemption equals

= .9935 x 30 mins + .006216 x [30 + 9] mins

= 30.047 mins

This implies mean service time increases by 2.84 secs.

If the maximum acceptable difference between service times under the two strategies is 15 secs, solving 30.25 + .9935 x 30 + .006216 (30+X) tells us X, the mean replacement time can be as great as 41.589 mins.

F. <u>Circumvention</u>

The policeman's job has certain inherent problems. He performs a reactive task that relies heavily on information from telephone callers. His job has an unstructured character in the sense that it would be extremely difficult to control what incidents the policeman will face and when they will occur. Consequently, he is permitted to use a great deal of personal discretion. This is certainly warranted, but it also provides the leeway for many problems. Also, it is very difficult for the dispatcher to maintain control of the system.

The dispatcher is at a disadvantage because he cannot know that a unit has completed servcing an incident until that unit reports to him that it has completed service. If the call that the unit was assigned to was unfounded the patrolman need not call back in service until he catches up on paperwork, gets a cup of coffee or a smoke, or even a short nap. In fact, any call for service can be extended within reasonable limits without arousing suspicion. Consequently, servers that are actually free for dispatching do not appear to the dispatcher to be free. System performance suffers whether the dispatching strategy is pre-

emptive or nonpreemptive.

Officer's discretion can also have profound effects on the dispatching strategy that is being used. When filing reports on incidents, the nature of many jobs coupled with the hassle of paperwork has created unofficial criterion by which jobs are identified as being "important" or "unimportant".

There is some validity to this notion. But there is also a legitimate question of how "important" is really defined. How often is the importance of an incident a function of the competence, laziness, prejudice or fatigue of the individual officer?

In fact, it is evident that the police even develop a personal scale of legitimacy for callers. It has been said to rank a middle class victim of a street attack as the most legitimate caller, followed by a middle class victim of burglary, then a lower class victim of theft with the lowest creditability being given to a lower class victim of assault. [62]

In both instances, no matter what dispatching strategy is in effect, official policy is circumvented, and the equity of law enforcement is degraded. But, if this attitude is carried into a preemptive dispatching strategy, it is not hard to imagine that the police might use preemption as an excuse to leave incidents that need their attention but they consider "dirty work" or a "hassle". This attitude could severely damage the effectiveness of preemption.

It must also be noted that there is often a fine distinction between discretion and prejudice, bias or stereotyping, although the effects may

be the same. If they do exist, they could affect whether a unit is dispatched to an incident, or how long it takes for that unit to be assigned. It may also influence how quickly the assigned unit responds. With a preemptive dispatching strategy these attitudes would be especially noticeable in the prioritization process.

It should also be remembered that if the patrolman does not like the new dispatching strategy it is within his control to disrupt the very technology that is meant to establish his professionalism. They can use alleged "dead spots" to miss transmitted messages. A pushed, or taped, transmitter button can drown out communication on an entire radio channel. The patrolman may even not answer a call, knowing that the dispatcher will call another unit.

In addition, the public can also destroy the effectiveness of a preemptive dispatching strategy. They have already found that saying a gun or knife is involved in an altercation will ensure quicker service. As more and more unwarranted urgent calls are received police service must decline, no matter what strategy is involved.

It is important that these issues are recognized when evaluating the feasibility of preemption. If a police force is particularly biased is undisciplined, perhaps preemption is not a viable alternative.

X. CONCLUSION

A. Discussion

Preemption is a dispatching strategy that can be used to provide better service for a selected group of customers at the expense or inconvenience of others. The purpose of this thesis has been to create a structure that could be used to evaluate and implement such a strategy for police dispatching.

An analytical approach has been stressed. Both Decision Theory and spatial modeling have been employed to clarify the problem that was being discussed and to provide a yardstick for measuring the changes that take place.

It is not anticipated that a preemptive dispatching strategy will be appropriate for everyone. We have discussed how although, it is not the most severe strategy that could be used to provide better service, it may, nevertheless, be hard for many citizens to accept. It is anticipated that preemption will be most useful when the public wants improved service, but remains rational about the capabilities of a public service bureaucracy. The fear of crime or the financial plight of the local community could have a dramatic effect on citizen attitude toward this strategy.

A number of assumptions and simplifications were made to make the model tractable. Others were made because the data that was needed to

perform the desired calculations was unavailable. As a result it was felt that extensive evaluation was not justified. Instead brief numerical results have been provided throughout the paper that have demonstrated a specific technique or idea.

The analysis remains important because the model illustrates a method of evaluating preemptive dispatching that leaves the reader with an understanding of preemption and what it involves.

The model shows how powerful a tool decision theory can be in analyzing complicated decision problems under uncertainty. The decision tree clearly defines the process that is being investigated and the stages that are deemed important. It emphasizes the alternate consequences of any action and the chance of their occurring.

Utility Theory compliments the decision tree with its ability to create multiattribute utility functions that can reflect the subjective and objective opinions of various groups. This structure serves to amplify the actual decision process because it is possible to identify which groups are influential in a decision and how they are weighted relative to one another. The utility function, itself, enables a d.m. to identify the tradeoffs that occur between groups or consequences.

In addition, the approach is mutually beneficial to both the administrator and public. While the public is pleased to be asked what service they want, it is also to the administrator's advantage, because the structure of decision theory allows him to substantiate

why a decision was made and since the public was involved in the decision making process they will be less inclined to disagree with the results.

A valuable perspective of the probabilistic alternatives of an action evolves. The d.m. no longer accidentally overlooks an important outcome. Furthermore, the structure allows a means to evaluate the sensitivity of the strategy to changes of the levels of any attribute. The analysis is much more meaningful than single consequence comparisons.

The outgrowth of this work is the small, easily programmed "package" that was discussed in the EVALUATION of Chapter Eight. The program evaluates a dispatching situation and provides the dispatcher with the best units to preempt. The package would be a valuable extension to a CAD system with AVM.

However, it is feasible that after extensive use in one or two cities, or the comprehensive analysis of many simulated situations, that trends in peemptive dispatching will emerge. It may be that units en route are never preempted or that when all constraints are met such that the dispatcher can preempt, he always will. Or, perhaps levels of specific attributes, such as JOB 2, TRAV 1 or TRAV 2, will always signal whether to preempt or not. In these cases "scenarios" of preemptable cases can be stored in the computer. It will no longer be necessary to evaluate utilities because experience has shown that it isn't necessary.

The ultimate simplification would be a set of decision rules that the dispatcher could memorize, or keep on a chart. CAD would be unnecessary. Smaller departments would only need to identify a larger department, whose characteristics were close enough to be acceptable, to obtain a usable strategy.

Besides the policy considerations that have just been discussed, there are other ramifications of the structure that was used. Decision Trees and GMUF's would be applicable for use in an aggregate evaluation of police service as well as in the disaggregate situation that has been described. A new function could be created and evaluated that would be capable of measuring the impact of over and under response on the system as a whole - i.e. the change to, the amount of preventive patrol, the number of arrests and the like.

B. Additional Research

Of course, there is a great deal of research that must be performed before a preemptive dispatching strategy can be properly evaluated and implemented. This was obvious in the number of assumptions and simplifications that took place in constructing the model.

(1) Cost curves will not be linear. More appropriate curves need to be assessed.

(2) The $M/G/\infty$ queuing system must be replaced by a model where queues do exist.

(3) Screening of calls for priority requires that data must be collected so that the important relationships between a call's source, type, duration and whether or not it is in progress can be identified.

(4) Better records of a police effort must be kept so that the outcome as a function of response time, such as the P(arrest/response time was 10 mins), can be determined.

The problem of creating the appropriate GMUF has created a number of other areas that need more study.

(5) The survey will be a major effort. Extensive evaluation and and pretesting will be required to establish a clear, unbiased, comprehensive questionnaire. The measures that are used to evaluate opinion must be carefully selected so that they are proper indicators of the system performance that is being analyzed. Obviously, the identification of the survey group itself will be a critical aspect.

(6) Then the function must be formed. Additional effort will be needed to determine how the decision process in a police bureaucracy is actually conducted so that it may be accurately modeled.

(7) Means of circumvention and secondary effects must also be analyzed. For instance: (a) Arrests may not increase with more rapid response times. (b) Police may use preemption to avoid disagreeable jobs. (c) Crimes may not be deterred, but, rather, pushed into neighboring areas, or the emphasis might shift to less serious crimes that don't receive intense attention. (d) More arrests may mean more

paperwork that reduces preventive patrol time. (e) Prejudice may disrupt the prioritization process.

(8) Finally, the last area of analysis must recognize the total cost of preemption in terms of the cost to hire an analyst, conduct a survey, and run the program. This must be weighed against the benefits of preemption.

C. Initial Police Actions

It is beyond the scope of this paper to determine specific conditions under which preemption should be used. However, this is not meant to imply that a police department cannot start a preemptive dispatching strategy until the recommended research is complete. Rather, it does suggest the appropriate considerations that should not be overlooked when initiating a preemptive dispatching strategy.

First, and above all, the preemptive strategy must be formally defined so that it can be properly evaluated. The goals of the strategy and the appropriate performance measures must be identified.

The approach should be gradual, beginning with obvious preemptive situations - such as sending an officer assigned to get a cat out of a tree, to chase a nearby robbery suspect, so that the implications of using a preemptive strategy can be understood with little chance of error, prior to venturing to a more refined stage. In addition, it is important that the secondary effects are not ignored. A myopic perspective can only limit the effectiveness of the preemptive strategy.

Specifically, there are a number of actions a police department can take to collect data and develop operational procedures that will help in implementing, and understanding the impact of, a preemptive dispatching strategy prior to actual implementation.

(1) Data should be collected that correlates the type of call and its source. A call's priority should be estimated by the dispatcher, and then compared to the patrolman's evaluation of the incident once it has been serviced. This will help to develop "keys" to use in identifying a calls urgency. A discussion session, between the dispatchers and the patrolmen, might identify situations that could benefit by preemption, as well as additional "keys" that the dispatcher could use in making these evaluations.

(2) Statistics could be gathered concerning the proximity of busy nonurgent units to an urgent call for service. Busy units might record their relative position to an urgent call and whether or not they could have left their assigned job, and what that job was. This would give patromen an opportunity to practice assessing if they could leave an incident, and it would provide the system with a measure of the expected gains in travel time due to preemption, as well as an idea of what jobs were amenable to preemption and what population might be impacted.

(3) A survey could be conducted within a city where preemption has been implemented, such as Rotterdam, to ascertain the benefits and disadvantages of the strategy.

D. Conclusions

The complexity of preemption has been described. A method of approaching and evaluating a strategy has been developed. The model does not completely destroy or replace existing strategies. Instead, it augments the existing system in an effort to ease the transition to a more responsive system. A gradual approach will allow testing of system response and experimentation with the type of information gathered and the circumstances under which proper inferences can be made. It is hoped that further study will be directed toward implementing this valuable strategy.

GLOSSARY

COMPLAINT OPERATOR (OFFICER) - The complaint operator answers calls for service. His job is to determine what the nature of the call is, where the incident occurred, who is calling and if the incident is still in progress. He determines the priority that is assigned to a call. He is a member of the communications division.

PRIORITY - The priority of a call represents its precedence in the dispatching scheme - in rank as compared to other calls. Calls are generally placed in two or three categories. The simplest form would be a distinction between urgent and nonurgent, or emergency and nonemergency calls. The priority is determined, using predetermined, specified criteria.

PRIORITY 1 - A priority one customer is a high-priority customer.

DISPATCHER - The dispatcher selects the car that is to be assigned to any incident. If special services are available he will determine if they are to be provided to an incident. He is a member of the communications division.

URGENT CALLER - An urgent caller is a caller who needs immediate attention. If special services are available he will receive this service. Under a preemptive dispatching strategy urgent calls will include current emergency calls, plus certain "in progress" a "suspect on the scene" crime and noncrime related calls.

SCREENING OF CALLS - The screening of calls by the c.o. separates out calls that have been predefined to be unimportant and not warranting service. They may be referred to a more appropriate service facility.

PRIORITIZATION OF CALLS - The prioritization of calls requires that the complaint operator determine a call's priority. Calls will be classified as urgent or nonurgent.

SPATIAL POISSON PROCESS - Homogeneous spatial poisson process $X(s)$ where parameter s denotes a bounded region of the plane, $X(s)$ has the probability distribution $P(X(s) = K) = \frac{(\lambda A(s))^k e - \lambda A(s)}{k!}$ for $A(s) \geq$, $k = 0, 1, 2.$

UTILIZATION (ρ) - Utilization is defined to be λ_i/μ_i. It represents the percentage of time a unit or force is busy, where $\lambda_i \equiv$ the rate of arrival of calls, and $1/\mu_i$ is the mean amount of time spent serving a call. If λ_i/μ_i is greater than 1, a unit is always busy.

$\underline{U_{out\ 1}(C)}$ - Name of the utility function which evaluates the outcome of the service that is received by a priority 1 customer. (Customer's viewpoint)

CONVICT - To prove or declare a suspect guilty of an offense, especially after a legal trial.

CHARGE - To accuse or blame a suspect of an offense.

ARREST - Taking of a suspect into custody in connection with a legal proceeding.

SCARE AWAY - To cause a criminal to flee the scene of a crime prior to completing the crime. This may be caused by the criminal hearing sirens, seeing police car lights, or hearing screeching brakes or the police on a bullhorn. The suspect is not caught.

TOO LATE - The police arrive after the suspect has left the scene. They in no way influenced his leaving.

NO SHOW - The police are dispatched to a call but do not arrive on the scene.

$\underline{U_{out\ 2}(C)}$ - Name given to the utility function that is used to evaluate the outcome of the service that is provided to the priority two, preempted customer. (Customer's viewpoint)

VICTIMIZED - The nonurgent customer has his service interrupted and during the interim - prior to a replacement arriving - he experiences an unpleasant consequence of preemption.

$\underline{U_{nerv\ 1}(C)}$ - The name given to the utility function that is used to evaluate the importance of the length of time an urgent customer must wait for service. (Customer's viewpoint)

$\underline{U_{nerv\ 2}(C)}$ - The name given to the utility function that is used to evaluate the importance of the length of time a nonurgent caller must wait until a replacement unit arrives. (Customer's viewpoint)

$\underline{U_{accu}(C)}$ - The name given to the utility function that is used to evaluate the importance of the accuracy of a police dispatching decision. This function measures the impact of call classification and dispatching judgement. (Police viewpoint)

PROPER - In a preemptive dispatching strategy when a preemptable situation exists, a proper response is when either (1) the call was urgent and the dispatcher preëmpted a busy caller or (2) when the call was nonurgent and the dispatcher does not preempt.

OVER - In a preemptive dispatching strategy when a preemptable situation exists, an over response is when the dispatcher preempts a busy nonurgent call for a nonurgent call. A unit arrives at the scene of a crime quicker than the urgency of the call dictates.

UNDER - In a preemptive dispatching strategy (1) when a preemptable situation exists and the dispatcher does not preempt for a non-urgent call or (2) when a call is not classified as urgent and is not considered for preemption but is an urgent call. A unit arrives at the scene of a crime slower than the urgency of the call dictates.

NO RESPONSE - The dispatcher does not assign a unit to the call.

$U_{trav\ 1}(C)$ - The name given to the police utility function that is used to evaluate the importance of the length of time it takes the police to travel to an urgent caller (POLICE VIEWPOINT).

$U_{trav\ 2}(C)$ - The name given to the police utility function that is used to evaluate the importance of the length of time it takes the police replacement unit to travel to the interrupted caller (POLICE VIEWPOINT).

$U_{job\ 2}(C)$ - The name given to the utility function that is used to evaluate the importance of the disruption prempting a nonurgent incident of a particular nature

CAT IN A TREE - A policeman is assigned to help get a cat out of a tree.

DRUNK - A policeman is assigned to escort a drunk person out of an exclusive area of the city.

SUSPICIOUS PERSON - A policeman is assigned to investigate a stranger's presence in some unusual location or at an unusual time.

LOCKOUT - A policeman is assigned to help a person who is locked out his home.

BURGLARY - A policeman is assigned to help a person who has been burglarized in the past (greater than 6 hours ago).

FAMILY QUARREL - A policeman is assigned to try to settle a family disturbance.

VEHICULAR ACCIDENT - A policeman is assigned to direct traffic at the scene of a vehicular accident.

$\underline{U_{PRECUSTO}(\underline{C}i)}$ - The name of the multiattribute utility function that is comprised of the four single attribute utility functions for the customer. It provides a single numeraire that describes the importance of any four attribute consequences of a dispatching action as seen by a customer.

$\underline{U_{PREPOLO}(\underline{C}i)}$ - The name of the multiattribute utility function that is comprised of the four single attribute utility functions for the police. It provides a single numeraire that describes the importance of any four attribute consequences of a dispatching action, as seen by the police.

$\underline{k_i\text{'s}}$ - The relative scaling factors used in forming multiattribute utility function which indicate the relative weighting given to the associated utilities of those attributes.

$\underline{U_{GRANDMUF}(\underline{C}i)}$ - The name of the group multiattribute utility function is comprised of the nested MUF's $U_{PREPOLO}(\ )$ and $U_{PRECUSTO}(\ )$. It measures the importance of the consequence of any dispatching action in terms of the system's overall values.

<u>MUF</u> - Multiattribute Utility Function,

<u>GMUF</u> - Group Multiattribute Utility Function.

Appendix A

SPATIAL DISTRIBUTION OF BUSY SERVERS IN A SPATIALLY ORIENTED M/G/∞ SERVICE SYSTEM

To describe an M/G/∞ service system we have made the following assumptions.

1. infinitely many servers
2. no in queue waiting time for customers
3. customers arrive in a Poisson manner with parameter λ
4. service times are independant and identically distributed with cumulative distribution function $H(x)$.
5. the mean service time $\frac{1}{u} = \int_0^\infty (1-H(x))d_x$
6. initially (at time $t=0$) there are no customers present

We will define the following:

$P_k(t) \equiv P[\text{at time } t \text{ there are exactly } K \text{ customers being served}]$

$\lim_{t \to \infty} P_K(t) = P_K$

We want to prove that busy servers in a (spatially oriented) M/G/∞ queuing system are distributed in a Poisson manner, or

$$P_K(t) = \frac{[\lambda \int_0^t (1-H(x))dx] \exp(-\lambda \int_0^t (1-H(x))dx)}{K!} \qquad K = 0,1,2,....$$

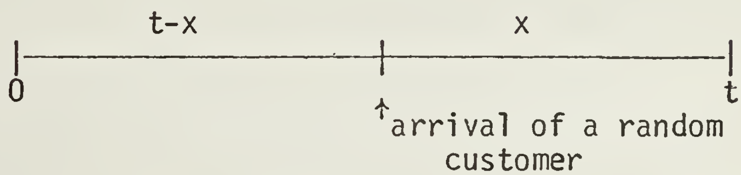
$$P_K = \frac{(\lambda/\mu)^K e^{-\lambda/\mu}}{K!}, \qquad K = 0,1,2,....$$

Let $P_k(t/n)$ = P[at time t there are exactly k customers being served given there are exactly n arrivals in the interval [0,t]]

then $$P_k(t) = \sum_n P_k(t/n) \frac{(\lambda t)^n e^{-\lambda t}}{n!} \qquad (1)$$

But, for a Poisson process, if there are exactly n arrivals in [0,t], the unordered arrivals are uniformly, indipendently distributed over [0,t].

Consider [0,t]



If a random customer arrives with x more time left in [0,t], then the probability he is still being serviced at t is (1- H(x)). But, the unconditional probability he arrives in [x,x+dx] is dx/t. Thus, the probability that a random customer which arrives any time in [0,t] is still being served at time t is:

$$\alpha = \int_0^t \frac{(1-H(x))}{t}\, dx \qquad (2)$$

We now use the fact that the unordered arrivals times are independent. Given n arrivals in [0,t] the probability that there are k customers being serviced at t :

$(k \leq n)$ is $\quad \binom{n}{k} \alpha^k (1-\alpha)^{k-n} \qquad (3)$

Substituting (2) and (3) into (1) we can show:

$$P_k(t) = \frac{[\lambda \int_0^t (1-1t)x))\, dx]^k \exp[-\lambda \int_0^t (1-H(x))\, dx]}{k!}$$

In a spatial context, in steady state, the probability there are k busy servers in a region of area A is:

$$P_k(A) = \frac{(\frac{\lambda A}{\mu})^k e^{-\frac{\lambda A}{\mu}}}{k!}$$

This says that, regardless of the method of prepositioning the units, the busy servers are distributed as a spatial Poisson process with parameter λ/μ busy servers per unit area, when the system has been described as a spatially oriented $M/G/\infty$ service discipline.

Appendix B

DEVIATION OF THE PROBABILITY OF n BUSY SERVERS BEING FOUND CLOSER THAN THE CLOSEST FREE UNIT

P [n nonurgent busy units are located closer than the closest free unit]

Intuitively this equals:

P[n nonurgent busy units are < f] · P[closest free at f]

$$\int_{f=0}^{\infty} \frac{(\rho_2 \pi f^2)^n \, e^{-\rho_2 \pi f^2}}{n!} \cdot \rho_f \pi 2f \, e^{-\rho_f \pi f^2} \, df$$

Let

$$u = \pi f^2(\rho_2 + \rho_f)$$

$$du = 2\pi f(\rho_2 + \rho_f) \, df$$

$$\frac{u}{\pi(\rho_2 + \rho_f)} = f^2$$

such that

$$= \int_{u=0}^{\infty} \frac{\left(\rho_2 \pi \cdot \frac{u}{\pi(\rho_2+\rho_f)}\right)^n}{n!} \cdot \rho_f \pi 2f \cdot e^{-u} \frac{du}{2\pi f(\rho_2+\rho_f)}$$

$$= \int_{u=0}^{\infty} \frac{\left(\frac{\rho_2 u}{\rho_2+\rho_f}\right)^n}{n!} \cdot \frac{\rho_f}{\rho_2+\rho_f} \cdot e^{-u} \, du$$

$$= \left(\frac{\rho_f}{\rho_2+\rho_f}\right) \left(\frac{\rho_2}{\rho_2+\rho_f}\right)^n \int_{u=0}^{\infty} \frac{u^n}{n!} e^{-u}\, du$$

But the integral is an Erlang distribution which equals 1.

So,

P[n nonurgent busy units are located closer than the closest free unit]

$$= \left(\frac{\rho_f}{\rho_2+\rho_f}\right) \left(\frac{\rho_2}{\rho_2+\rho_f}\right)^n \quad [1]$$

Appendix C

DISCUSSION OF NO SHOW AND NO RESPONSE

NO SHOW/NO RESPONSE

NO SHOW has been defined to be the situation where a unit has been dispatched to an incident but it does not arrive. NO RESPONSE has been defined as the situation where the complaint operator accepts the call but no unit is dispatched to the incident. In either case, the customer does not receive service.

NO RESPONSE and NO SHOW are the worst imaginable levels of OUT 1 and ACCU. They must be defined so that the utility function can be evaluated (see Appendix D), but this does not mean that the consequences will occur, only that they are imaginable. They affect TRAV 2, NERV 2, NERV 1, TRAV 1.

The problem that should be recognized is that under a preemptive dispatching strategy a NO SHOW can occur to either the urgent or preempted customer, or both. Under a nonpreemptive strategy only the urgent customer could be affected.

If we assume the probability of NO SHOW is small, but that it is equally likely that either the urgent or preempted customer does not receive service, then the preemptive dispatching strategy will be seen in an unfavorable perspective.

On the other hand, if the probabiity of NO SHOW is not small, and it is assumed that either the urgent or preempt customer, but not both does not receive service, then preemption receives an overly favorable bias.

Nevertheless, for the purposes of this initial model we will assume that all calls are always answered and will receive service. It is felt that this is a reasonable assumption because:

(1) It is assumed that in an M/G/∞ model that there is no excuse for a call not receiving service. There is no pressure on the dispatcher to ignore calls - to reduce workload. Any such action would be inconsistent.

(2) The dispatcher should never forget to answer a call because an intelligent CAD system [63] would remind him of unserviced incidents and (3) patrol units should always respond to assigned calls because administrative procedures can be tailored to prevent any unauthorized breaks.

The branches NO SHOW and NO RESPONSE will not appear on the modified Decisiton Tree in Chapter 3.

Appendix D

DETAILS OF DECISION THEORY

Decision Analysis provides a means to systematically approach a decision problem under uncertainty. The details of the background and underlying theory can be found in Raiffa.[64]

It is appropriate when evaluating police dispatching strategies because there are many alternatives involved and the outcomes are uncertain. It is an excellent tool to use to organize a problem and eliminate unnecessary guess work.

A decision analysis approach can be broken into four phases.

(1) define the problem

(2) evaluate uncertainties

(3) scale preferences for consequences

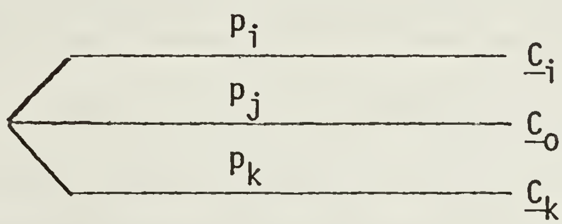
(4) evaluate the alternatives.

Defining the problem involves identifying the objectives and critical people involved, and structuring the information flow. The attributes that will act as performance measures are selected. A consequence of an action will consist of a vector of attributes. For instance $\underline{C}i = (Vi, Wi, Oi)$ might describe one set of consequences - set i, of a police response where Vi is travel time, Wi is the number of cars employed, and Oi is whether the criminal was apprehended or not.

Then the uncertainties must be evaluated. The probabilities of various possible outcomes must be determined. Measurements may be

subjective or objective. Models are a valuable tool that can be used to develop the necessary predictive data.

The uncertain consequences of an alternative can be described by a vector ($\underline{C}i$, pi, $\underline{C}_j$, $p_j, \ldots, \underline{C}_k, p_k$) where p_i is the probability that the condition of the system after choosing alternative i is $\underline{C}_i$. The vector represents the probabilistic outcome which is diagrammed below (a lottery)



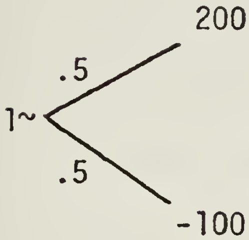
Scaling the d.m.'s preferences requires the assessment of his utility over a set of vectored consequences. The $U(\underline{C}_i) \equiv U(V_i, W_i, D_i)$. When more than one attribute is involved the function is called a Multiattribute Utility Function (MUF).

Evaluating the various alternatives requires computing the expected utility of all consequences to determine the best alternative.

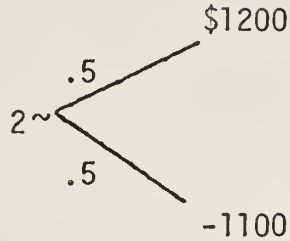
In the case of preemption the problem has been defined and a model has been created to evaluate uncertain outcomes. The scaling of preferences is the next step.

The St. Petersburg Paradox, due to Bernoulli, in Luce and Raiffa, p. 20 [65] demonstrates that expected value is not always an appropriate guide to behavior.

We might also examine two simple lotteries.



and,



Although the expected value is $50.00 most d.m.'s would not be indifferent between the two. Because there is a meaningful difference in the possible loss between lottery one and lottery two, expected value is not an accurate guide to behavior.

Utility theory was developed to define a function (call it a utility function) such that the expected value of a utility corresponds to the utility of the entire situation. von Neumann and Morganstern subsequently developed a vigorous set of axioms which show that in a situation with an uncertain outcome, the utility is precisely the expected utility of the probabilistic outcomes.[66] Utilities represent the intrinsic worth of an attribute or alternative, they are a cardinal measure of goodness.

Now one alternative is better than another only if its expected utility is greater than the other's. The specific conditions that must be met for a function to be a utility function can be found in Luce & Raiffa.[67] These conditions contain all information that is necessary to evaluate a utility function.

Where more than one attribute is used to describe any particular consequence the utility function is known as a Multiattribute Utility Function (MUF). A multiattribute consequence can be evaluated in

the same manner as the single attribute functions that were described before. The difficulty that arises is that the indifference points representing various consequences, that are required for the evaluation, are hard to determine.

As the d.m. tries to evaluate two multiattribute consequences to see if one is indifferent to the other, the interactions between attributes becomes confusing. Theoretically, the assumptions are justifiable, but from a practical standpoint it is questionable whether or not consistent assessments can be made.

Consequently, much work has been done to identify unique functional forms that can be computed using simpler evaluations and which are subject to less rigorous constraints.

Much work in this area has been done by Keeney.[68] He decomposes the MUF into single functions over each attribute. None of the conditions require the d.m. to consider preference tradeoffs between more than two attributes simultaneously, or to consider lotteries with the level of more than one attribute being varied. These conditions imply the MUF has an additive or multiplicative form.

The two assumptions that are required are (1) preferential independence and (2) utility independence. These results are found in Keeney.[69]

Preferential Independence: The pair of attributes (X_1, X_2) is preferentially independent of the other attributes $(X_3,\ldots,X_n)$ if

preferences among (X_1, X_2) pairs given that $(X_3, \ldots, X_n)$ is held fixed, do not depend upon the level where $X_3, \ldots, X_n)$ are fixed.

This implies that tradeoffs between attributes X_1 and X_2 do not depend on $(X_3, \ldots, X_n)$.

Utility Independence: The attribute X, is utility independent of the attributes $(X_2, \ldots, X_n)$ if preferences among lotteries over X_1 (lotteries with uncertainty about the level of X_1 only) given $X2, \ldots, X_n$ are fixed, do not depend on the level of these attributes fixed.

The main result is:

Thm 1. For $n \geq 3$ if for some X_i, (X_i, X_j) is preferentially independent of the other attributes $j \neq i$, and X_i is utility independent of all other attributes, then either

$$U(\underline{X}) = \sum_{i=1}^{n} K_i U_i(X_i) \qquad (1) \quad \text{Additive}$$

$$1 + KU(\underline{X}) = \prod_{i=1}^{n} [1 + Kk_i U_i(X_i)] \qquad (2) \quad \text{Multiplicative}$$

where

(i) U and U_i are utility functions scaled from zero to one,

(ii) the K_i's are scaling constants with $0 < K_i < 1$, and

(iii) $K > -1$ is a non-zero scaling constant satisfying the equation

$$1 + K = \prod_{i=1}^{n} (1 + Kk_i)$$

(K is known as BIGK)

Thm 2. For n=2 if X_1 is utility independent of X_2 and X_2 is utility independent of X_1, then the utility function $U(X_1, X_2)$ is either additive or multiplicative.

Using (1) or (2) from Theorem 1 if $\sum_{i=1}^{n} K_i = 1$ the utility function is additive.

Thus, for a utility function to be additive or multiplicative it is necessary to assess only the utility independence for one attribute and preferential independence for every pair of attributes that includes that one.

To assess an n attribute MUF, it is only necessary to assess n scaling constants and n single attribute utility functions.

The result is applicable if the attributes are scalars or vectors. If an attribute is a vector, the utility function will be called a <u>nested</u> MUF.

There are many standard assessment processes for single attribute utility functions, one can be found in Raiffa.[70] To determine the unknown K_i's it is necessary to create and solve n independent equations in n unknowns.

The equations are formed by having the d.m. pick two consequences on lotteries between which he is indifferent. The expected utility of these alternatives are determined using (1) or (2) of Thm.1 and set equal to one another. A comprehensive example of the questions that may be asked and the subsequent evaluation can be found in Kirscher.[71]

This process can be difficult and tedious. The equations need not be linear. The feedback during an evaluation is slow. Extreme point evaluations which are asked to simplify computations are very difficult to assess. Thus, an interactive computer program for assessing and using multiattribute utility functions are developed by Alan Sicherman to alleviate those difficulties.[72]

The program was used for all evaluation of preemptive dispatching MUFs. It is appropriate whenever the preferential independence and utility independence assumptions held. In fact, it is often reasonable to assume an additive or multiplicative form, although the requisite assumptions do not hold exactly. Keeney discusses the practicality of these forms for $n \geq 4$ and as approximations in[73].

INDIF 2 and INDIF 1 are the two commands in the program that are used to assess the relative importances of the particular performance measures and their interdependences.

In many decision making situations the final decision will weigh the opinions of more than one person. Thus in keeping with the work done to this point we would want to create a single numeraire

that appropriate weights the opinions of the people whose utilities are assessed.

In general there are two methods available to approach this problem

(1) Group Bayesian approach

(2) Pareto optimality [74]

The problem is that although each approach is reasonable they give different results. Consequently each should be considered and the one that most accurately reflects the decision makers feelings should be chosen.

The group Bayesian approach will be used in these calculations because it is felt that it is desirable to maximize the utility of the group rather than the utilities of the individuals.

Specifically, when evaluating the Multiattribute Utility Functions named PRECUSTO and PREPOLO a number of people will be sampled. This entails forming a Group Multiattribute Utility Function (GMUF).

It is not felt that one individual's opinion is more correct than another's. Furthermore, there is no reason to believe that one citizen should be influenced by another so that they are all mutually utility independent. Thus each will be an additive GMUF with the Ki's = 1/N, where N is the number of people interviewed.

An interesting question that remains, however, is whether or not a citizen can answer questions about urgent and nonurgent situations simultaneously, in an unbiased manner, or whether it is more accurate

to ask him questions first as an urgent customer, then as a nonurgent customer and weight the two afterwards.

This example serves to emphasize two different human reactions to need. One is altruistic, the other selfish. Does a customer who is being robbed care about the inconvenience a nonurgent customer is experiencing so that preemption can occur? Will the urgent customer even care in retrospect?

If a certain "conscienceness" exists, such that the urgent customer wants help, but not at too high a cost for the nonurgent customer (and vice versa), I think the citizens being questioned can wear "both hats". One set of attributes will not always completely dominate the other. On the other hand, if a selfishness exists, conceptualizing two distinct groups of citizens is probably more appropriate.

For the first cut, I am assuming a certain empathy will exist between customers because the scarce police resources that have suggested preemption have caused a public awareness of the amount of service that can be provided. An urgent customer doesn't want the nonurgent customer's customer's service to suffer "too much". This implies that the customer is capable of maintaining a perspective of the needs of both the urgent and nonurgent customers.

The evaluation of GRANDMUF is a bit different however. For simplicity we will assume that there exists an arbitrator who assesses a MUF-GRANDMUF composed of two "attributes" PRECUSTO and

PREPOLO. Thus we have a nested GMUF. It is not unreasonable to assume the d.m. believes these two GROUPS are mutually utility independent. Thus the form of the nested group MUF is additive or multiplicative.

Now we can perform an evaluation of the indifference between lotteries, the same process that was described before, to ascertain which form is correct.

Let

$$L_1 \equiv \begin{cases} .5 & \text{PRECUSTO at best, PREPOLO at best} \\ .5 & \text{PRECUSTO at worst, PREPOLO at worst} \end{cases}$$

$$L_2 \equiv \begin{cases} .5 & \text{PRECUSTO at best, PREPOLO at worst} \\ .5 & \text{PRECUSTO at worst, PREPOLO at best} \end{cases}$$

NORMALLY if $L_1 \sim L_2$ the form is additive

OTHERWISE it is multiplicative.

But in this situation it is nonsensical to think about an outcome of PRECUSTO at its best and PREPOLO at its worst. Even though it has been assumed that the police and customer's opinions are completely independent it is hard to visualize a situation where the police feel that all attributes are not at their best and the customer finds all attributes are at their worst levels.

So, for a first cut it is assumed that the form of GRAND MUF is additive. If the results look reasonable it will be accepted, as that is the ultimate test.

Example of utility independence and preferential independence. For preferential independence X_{ij} must be preferential independent of X_{ij} for all $j \neq i$, $i = 1\text{-}4$.

We will pick OUT 1 as X_i, so the various X_{ij} pairs are

I. OUT 1, NERV 1

II. OUT 1, OUT 2

III. OUT 1, NERV 2

The general question that must be asked is

		OUT1	NERV1	NERV2	OUT2		OUT1	NERV1	NERV2	OUT2
I.	if	scare away	20mins	victimized	45mins	∿	too late	5mins	victimized	45mins
	is	scare away	20mins	not victimized	10mins	∿	too late	5mins	not victimized	10mins

in each case OUT 1, NERV 1 remain fixed, while OUT 2, NERV 2 are permitted to vary. In the first case, OUT 2, NERV 2 were relatively

poor. In the second situation they were relatively good. If the indifferences hold up through evaluations like I, II, and III, preferential independence has been demonstrated.

	OUT1	OUT2	NERV1	NERV2		OUT1	OUT2	NERV1	NERV2
II.	if charge	victim	20mins	45mins	∿	too late	not victim	20mins	45mins
	is charge	victim	5mins	10mins	? ∿	too late	not victim	5mins	10mins

	OUT1	NERV2	NERV1	OUT2		OUT1	NERV2	NERV1	OUT2
III.	if scare away	8mins	25mins	victim	∿	too late	6mins	25mins	victim
	is scare away	8mins	5mins	not victim	? ∿	too late	6mins	5mins	not victim

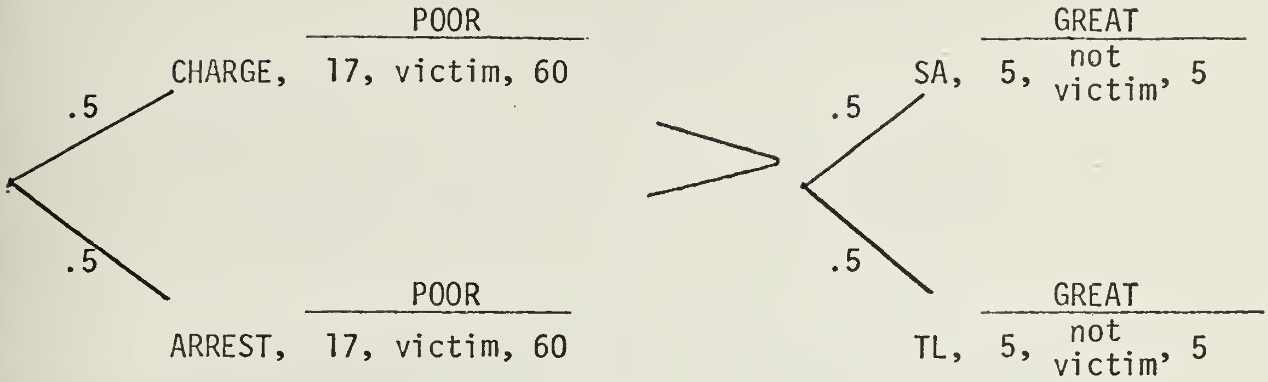
Utility Independence

Now we must show the utility independence of OUT1. As OUT1 changes and NERV1, OUT2, NERV2 are held fixed, the preferences of the lotteries cannot change with X_i.

Thus if:

$$\left\langle \begin{array}{l} .5 \quad \text{CHARGE, 7, } \frac{\text{GOOD}}{\text{not victim}}\text{, 5} \\ \\ .5 \quad \text{ARREST, 7, } \frac{\text{GOOD}}{\text{not victim}}\text{, 15} \end{array} \right. \quad > \quad \left\langle \begin{array}{l} .5 \quad \text{SA, 7, } \frac{\text{GOOD}}{\text{not victim}}\text{, 5} \\ \\ .5 \quad \text{TL, 7, } \frac{\text{GOOD}}{\text{not victim}}\text{, 5} \end{array} \right.$$

then,



Different lotteries must be evaluated over various combinations of OUT1 and then vary OUT2, NERV1, NERV2 from GREAT to POOR in an attempt to drive the preference in the other direction. If the preference does not change, utility independence has been shown.

Appendix E

COMPUTER PROGRAM USED FOR SPATIAL SIMULATION

```
      Dimension X(200),Y(200),Z(200),DX(100),DY(100),DS(100),DSO(100),
     XDS1(100),DS2(100),PRE(100),DIF(100),R(100),XELIG(100),YELIG(100),
     XXO(100),YO(100)
      N=200
 10   READ (5,*) A,D,C,F,B
      NSTART=A
      CALL RANDS  (NSTART,X,N)
      NSTART=D
      CALL RANDS (NSTART,Y,N)
      NSTART=C
      CALL RANDS (NSTART,Z,N)
      FREE=F
      BUSY=B
 90   READ (5,*)  CLX,CLY
      IF  (CLX.GT.  1.0)  GO TO 100
      IF  (CLX. LT. 0.0)  GO TO 110
      DO 95 I=1,100
      DX(I)=(X(I=100)-CLX)**2
 95   DY(I)=(Y(I=100)-CLY)**2
      DO 112 I=1,100
112   DS(I)=DX(I)+DY(I)
      DO 60 I=1,100
      DSO(I)=66
      DS1(I)=77
      DS2(I)=88
      XO(I)=100
      YO(I)=100
      IF  (Z(I+100).LE.BUSY)  GO TO 1000
      DS2(I)=DS(I)
      GO TO 60
1000  IF  (Z(I+100).LE.FREE)  GO TO 1500
      DS1(I)=DS(I)
      GO TO 60
1500  DSO(I)=DS(I)
      XO(I)=X(I+100)
      YO(I)=Y(I+100)
 60   CONTINUE
      FMIN=999
      DO 160  I=1,100
```

```
160  IF  (DSO(I).LT.FMIN)  FMIN=DSO(I)
     DO 170  I-1,100
     PRE(I)=99
170  IF  (DS1(I).LT.FMIN)  PRE(I)=SQRT(DS1(I))*10
     SFMIN=SQRT(FMIN)*10.
     QPRE=1000
     DO 175 I=1,100
175  IF  (DS1(I).LT.QPRE)  QPRE-DS1(I)
     DQPRE=SQRT(QPRE)*10
     WRITE  (6,115)
     WRITE  (6,120)  CLX,CLY, F,B
     WRITE  (6,125)  SFMIN,DQPRE
     DO 200  I=1,100
     DIF (I)=.1
     IF  (PRE(I).LT.25)  DIF(I)=SFMIN-PRE(I)
200  CONTINUE
     DO  210  I=1,100
     R(I)=210
     XELIG(I)=50
     YELIG(I)=50
     IF  (DIF(I).LE..125)  GO TO 210
     R(I)=((1.2*DIF(I))-.075)/.6
     XELIG(I)=X(I+100)
     YELIG(I)=Y(I+100)
210  CONTINUE
     DO  555  I=1,100
     DO  555  J=1,100
     IF  (XO(J).GE.2)  GO TO 555
     IF  (XELIG(I).GE.2)  GO TO 555
     FIRST=SQRT((XO(J)-XELIG(I))**2+(YO(J)-YELIG(I))**2)*10
     IF  (FIRST.GE.R(I))  GO TO 555
     SND=SQRT((XO(J)-CLX)**2+(YO(J)-CLY)**2)*10
     IF  (SND.LE.SFMIN)  GO TO 555
     DBUFR=SQRT((XO(J)-XELIG(I)**2+(YO(J)-YELIG(I))**2)*10
     WRITE  (6,733)  PRE(I),DBUFR,XO(J),YO(J),XELIG(I),YELIG(I)
555  CONTINUE
115  FORMAT  (5X,'CALL LOCATION',5X,'UTILIZATION')
120  FORMAT  (3X,4E11.4)
125  FORMAT  (2(8X,E11.4))
733  FORMAT  (6(5X,E11.4))
     GO TO 90
100  GO TO 10
110  STOP
     END
```

Appendix F

COMPUTER PROGRAM USED TO EVALUATE MUF'S

```
      DIMENSION U(8),KG(2),KI(8),BK(2),BG,IFLAG
      READ  (5,*)  (KI(J),  J=1,8) [PRECUSTO]
      READ  (5,*)  (KG(J),  J=1,2) [PREPOLO]
      READ  (5,*)  (BK(J),  J=1,2) [KPRECUSTO, KPREPOLO]
      READ  (5,*) BG [KGRANDMUF -BIG K]
      IALT=0
      IFLAG=0
 1000 READ  (5,*)  ((U(J),  J=1,8),IFLAG)
      IF  (IFLAG.EQ.1)  GO TO 2000
      IALT=IALT+1
C     PREPOLO
      TEMP1=1
      DO  10  J=1,4
   10 TEMP1=TEMP1*(1.+BK(1)*KI(J)*U(J))
      TEML1=(TEMP1-1.)/BK(1)
C     PRECUSTO
      TEMP2=1
      DO  20  J=5,8
   20 TEMP2=TEMP2*(1.+BK(2)*KI(J)*U(J))
      TEMP2=(TEMP2-1.)/BK(2)
c     GRANDMUF
      GMUF=KG(1)*TEMP1+KG(2)*TEMP2+BG*KG(1)*KG(2)*TEMP1*TEMP2
      WRITE  (6,100)   IACT,GMUF
  100 FORMAT  (5X,'ALTERNATIVE',I3,2X,'UTILITY=',F5.3)
      GO TO 1000
 2000 STOP
      END
```

ENDNOTES

[1] Science and Technology, p. 1.

[2] Kolesar.

[3] Science and Technology, p. 93.

[4] Saunders, p. 1.

[5] Dahl, p. 262.

[6] Saunders, p. 9.

[7] Ibid., P. 168.

[8] Larson [ref. 24], p. 63-64.

[9] Science and Technology, p. 1pl.

[10] Wilson, O.W.

[11] Gourley.

[12] Growther.

[13] Karlin.

[14] Cox and Smith.

[15] Feller.

[16] Larson [ref. 24].

[17] Campbell.

[18] Larson [ref. 26].

[19] Larson [ref. 27].

[20] Larson [ref. 23].

[21] Jarvis.

[22] Larson [ref. 23].

[23] Cobham.

[24] Heathcote.

[25] Christie.

[26] Stephan

[27] Conway

[28] Larson [ref. 25].

[29] Larson [ref. 23].

[30] Larson [ref. 25].

[31] Raiffa.

[32] von Neumann and Morganstern

[33] Keeney [ref. 17].

[34] Keeney [ref. 18].

[35] Kirkwood.

[36] Gorry.

[37] Schlaifer.

[38] Keeney [ref. 19].

[39] Kirsher.

[40] Keeney [ref. 7].

[41] Hauser.

[42] Saaty, p. 89.

[43] Larson, p. 19.

[44] Note: The police force can reduce communication delay, but initial reporting delay can only be improved through a successful public relations program. If the initial reporting delay is too great the potential effectiveness of preemption will be severely impaired.

[45] Thomas, p. 50.

[46] von Neumann and Morganstern

[47] Raiffa, p. 10.

[48] Saaty, p. 89.

[49] Stevenson.

[50] Science and Technology, p. 94.

[51] Ibid., p. 93.

[52] Bauer, p. 126.

[53] Sellin and Wolfgang.

[54] Marx.

[55] Science and Technology, p. 164.

[56] Ibid., p. 93.

[57] Hauser, p. 23-34.

[58] Keeney [ref. 17, 18, 19, 20].

[59] Sicherman, abstract.

[60] Karlin, p. 183-184.

[61] Saaty, p. 89.

[62] Wilson, J., p. 27.

[63] Johns.

[64] Raiffa.

[65] Raiffa, p. 20.

[66] Raiffa, p. 66.

[67] Luce, p. 39.

[68] Keeney [ref. 19].

[69] Keeney [ref. 19].

[70] Raiffa.

[71] Kirscher.

[72] Sicherman.

[73] Keeney, [ref. 17].

[74] Raiffa, p. 199-237.

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